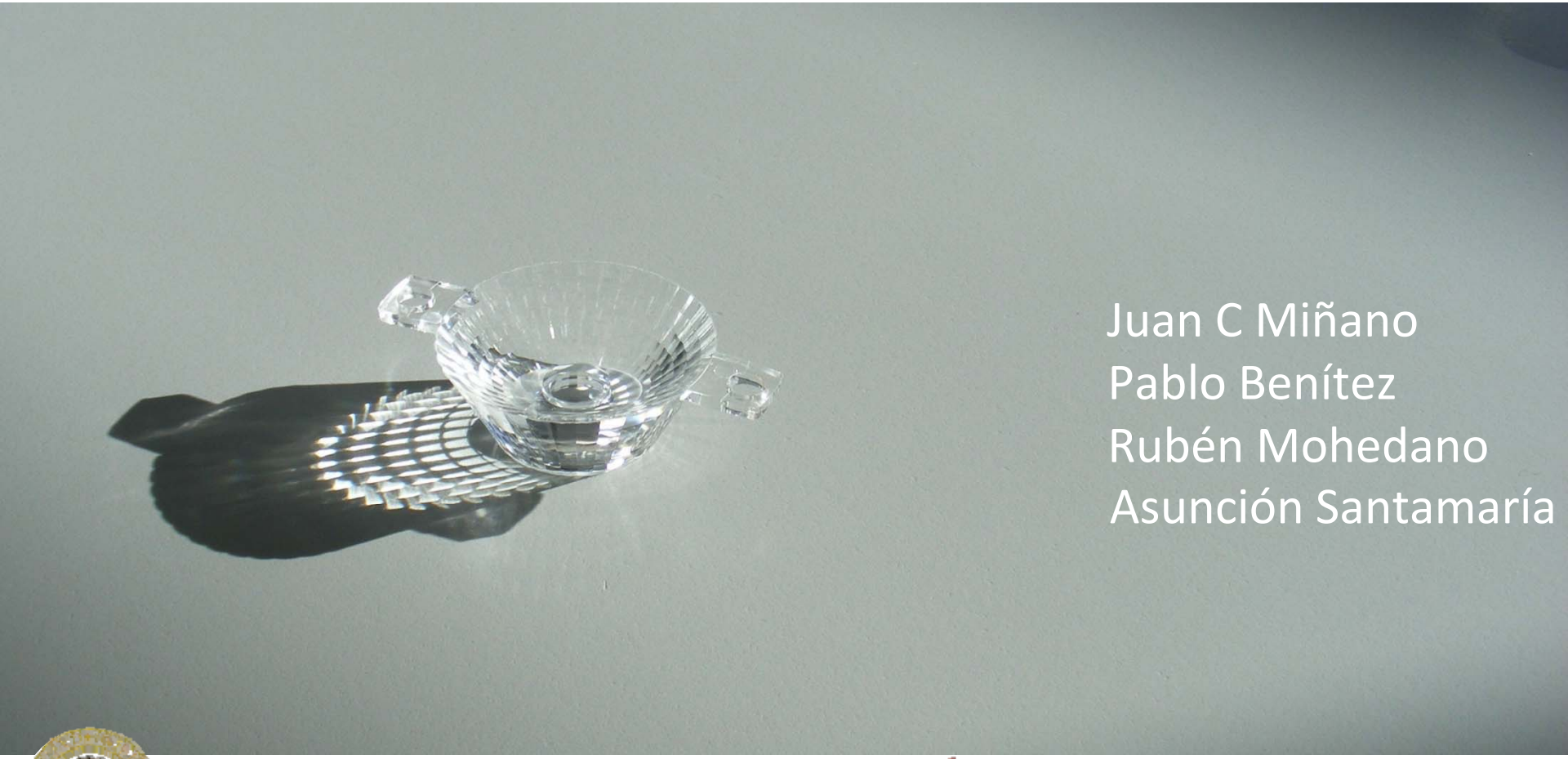
Advances in Optics for Solid State Lighting



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Outline

- Optics and LEDs
- Design Methods
- Design examples
- Conclusions

Outline

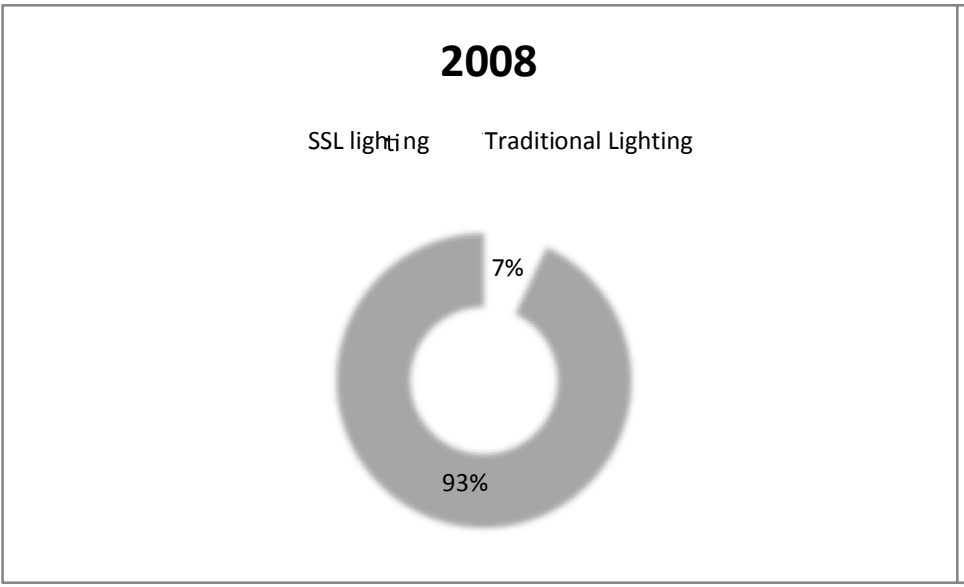
- **Optics and LEDs**
- **Design Methods**
- **Design examples**
- **Conclusions**

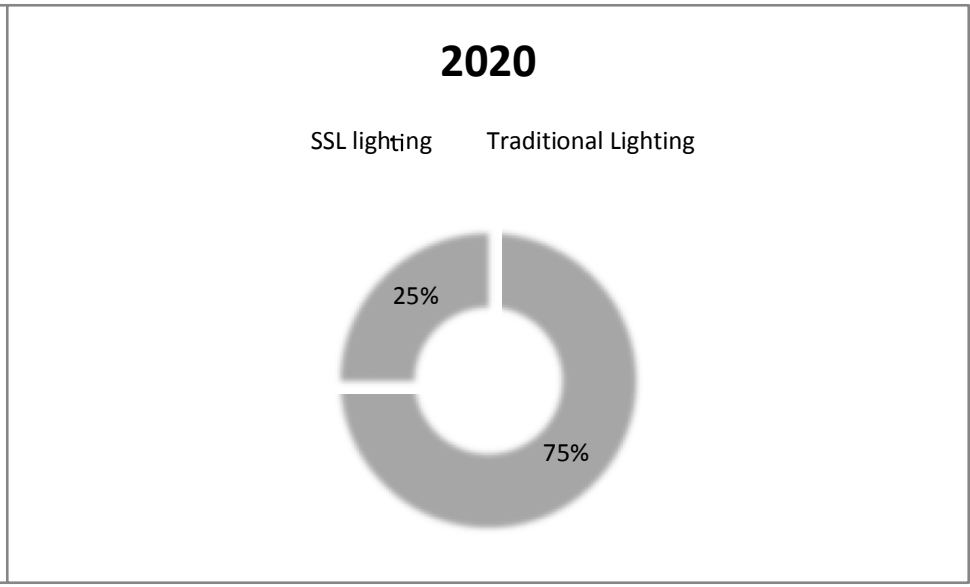
LEDS

- **Features**
  - **White color >130 lm/W (and by mm^2), ± 90° beam typically**
  - **Lots of colors**
  - **Low power consumption and long lifetime**
  - **Instant switch on/off**
- **Specific challenges**
  - **Flux and luminance (depends on the application)**
  - **Thermal**
  - **Cost**
  - **Non uniformities (multichip packages)**
  - **Retrofitting?**

Solid State Lighting

- Features
  - All applications (indoor/outdoor, accent, automotive, signaling…)
  - Imperfect results in the most demanding applications and retrofitting

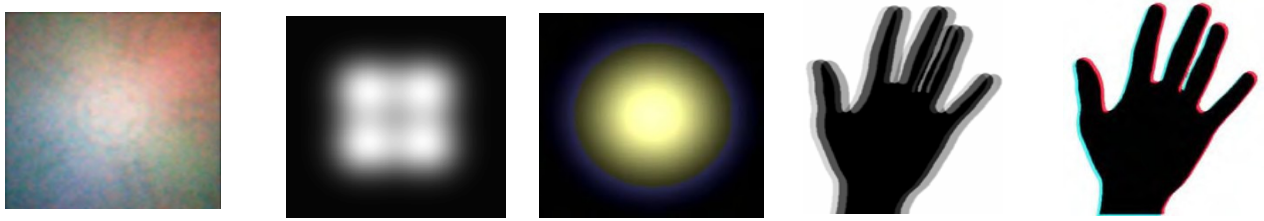




Solid State Lighting

- **Features**
  - **All applications (indoor/outdoor, accent, automotive, signaling…)**
  - **Imperfect results in the most demanding applications and retrofitting**
- **Specific challenges**
  - **Applications demanding high luminance**
  - **LED nature (emitting angles, thermal, costs)**
  - **Color mixing, illuminance uniformity and beam aesthetic goals**

LED + luminaries



White point shift | Intensity Artifacts | Color Fringes | Multiple Shadows | Color Shadows

Optics

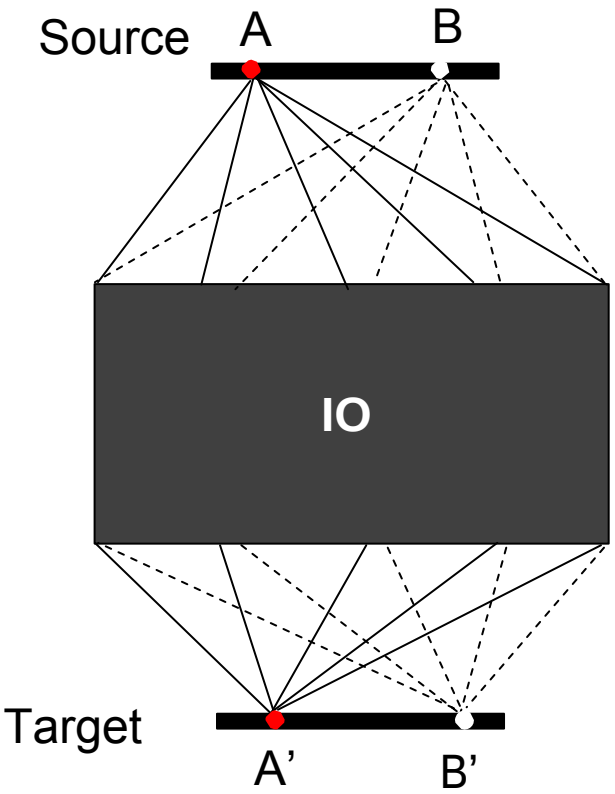
- Features
  - Primary optic + LED = light engine
  - Secondary optics = luminaire
- Manufacturing
  - Injection molding (PMMA and PC mostly)
  - Casting (silicone rubbers for domes)

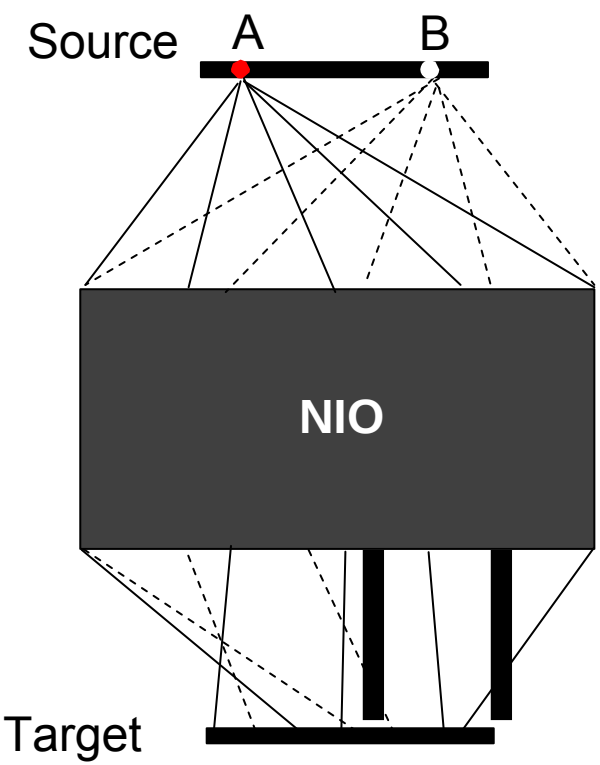
Outline

- Optics and LEDs
- **Design methods**
- Design examples
- Conclusions

Non-imaging Optics (NIO)

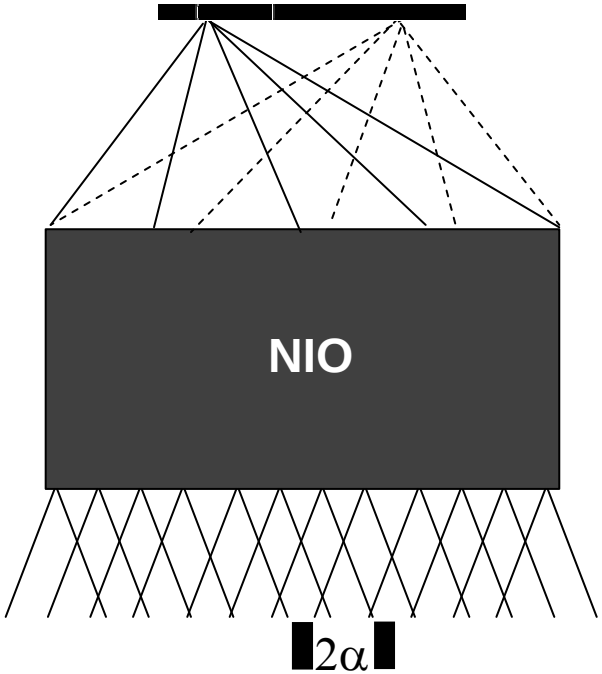
- **Features**
  - **Light power transfer between a source and a target**



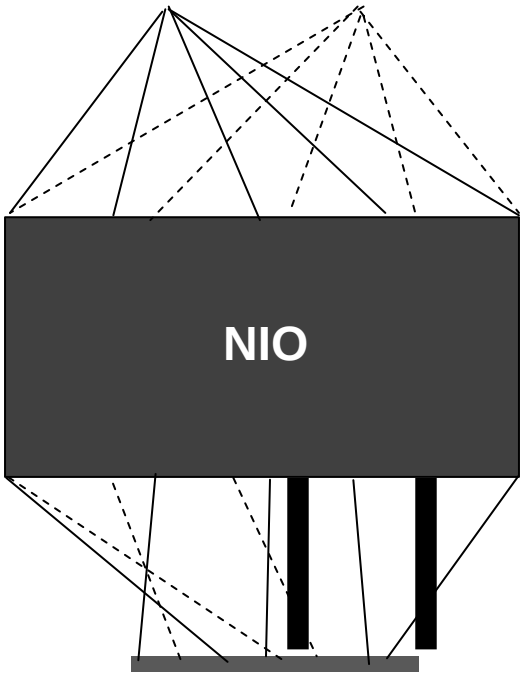


Non-imaging Optics (NIO)

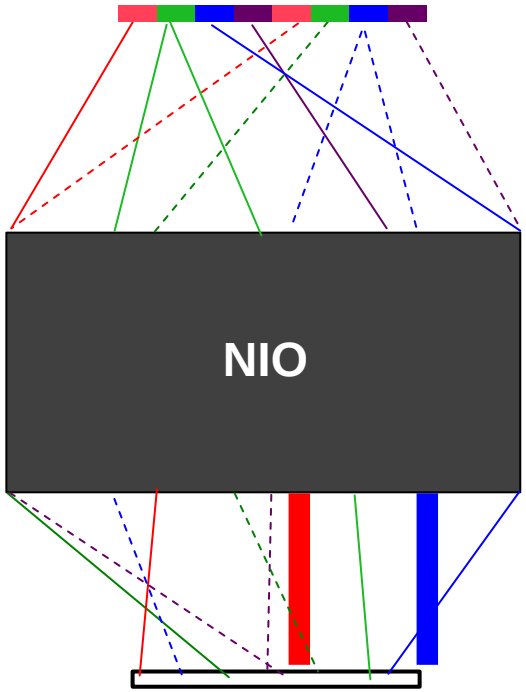
- **Features**
  - **Light power transfer between a source and a target**



Controlled beam angle



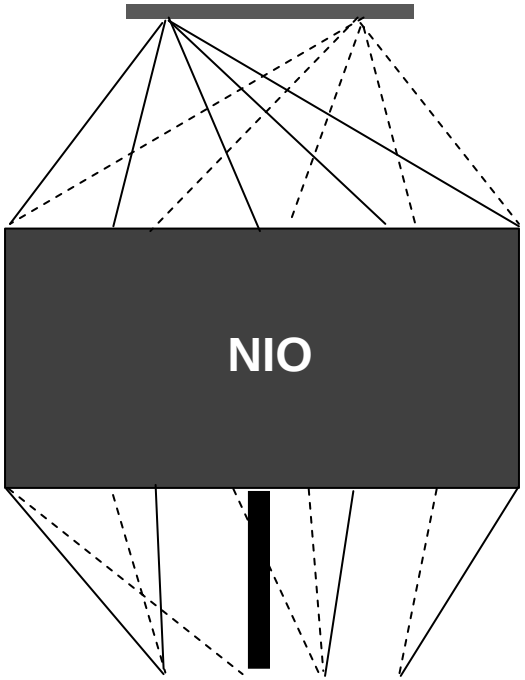
Uniform illuminance



Color mixing

Non-imaging Optics (NIO)

- **Features**
  - **Light power transfer between a source and a target**

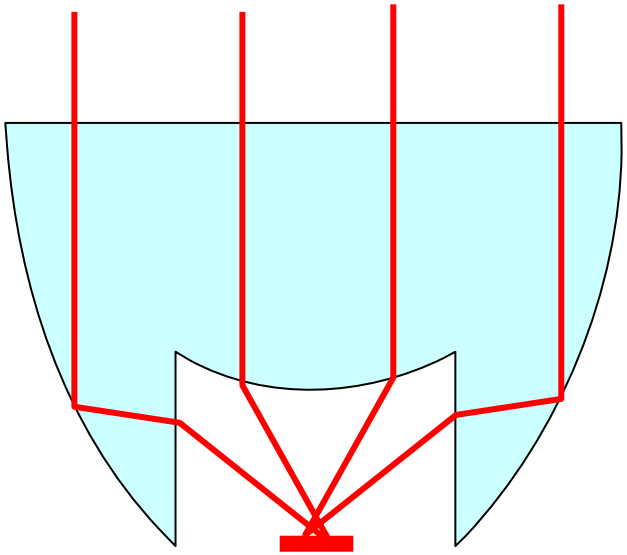


Fancy illuminance

Non-imaging Optics

- **Features**
  - **Light power transfer between a source and a target**
  - **Without the need of imaging, new possibilities arise: more efficient/compact/low cost optics…**

Photon funnel

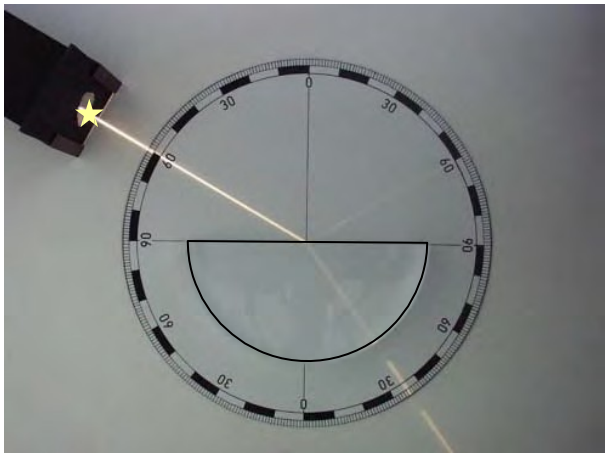


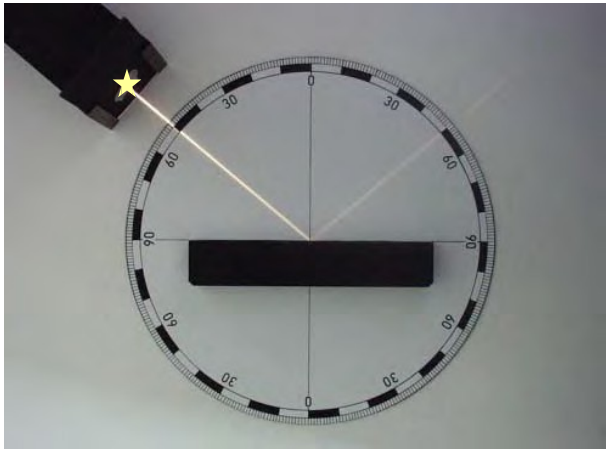
Non-imaging Optics

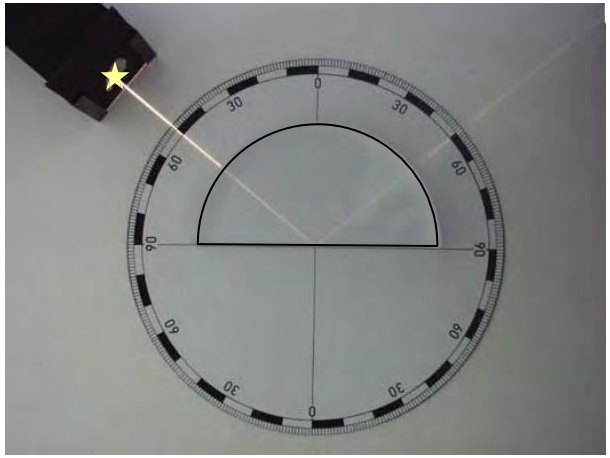
- **Features**
  - **Light power transfer between a source and a target**
  - **Without the need of imaging, new possibilities arise: more efficient/compact/low cost optics…**

Non-imaging Optics

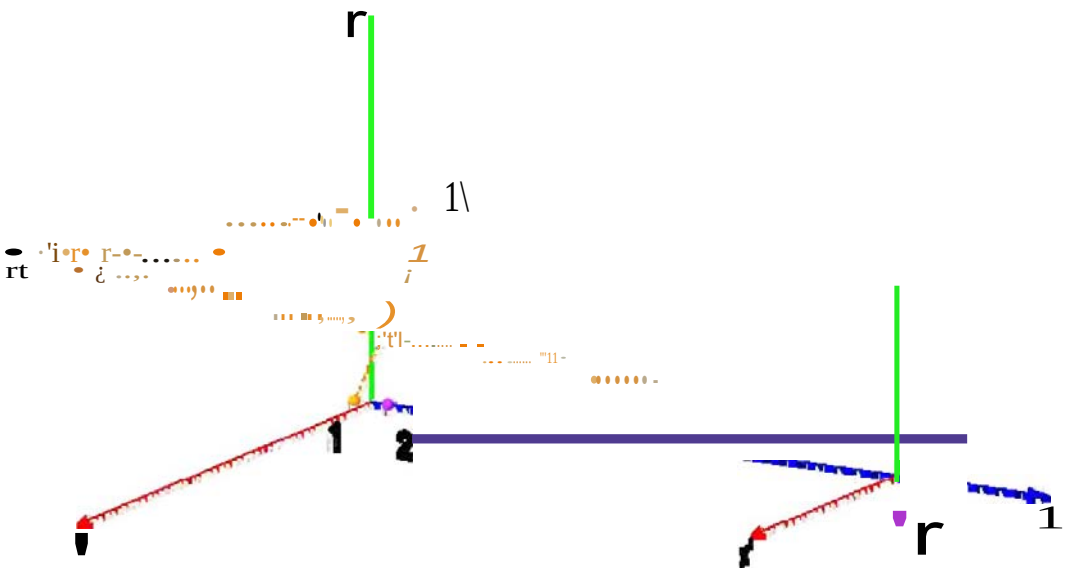
- **Design**
  - **Fermat's principle and derived/other physical laws: refraction, reflection and total internal reflection (TIR)**



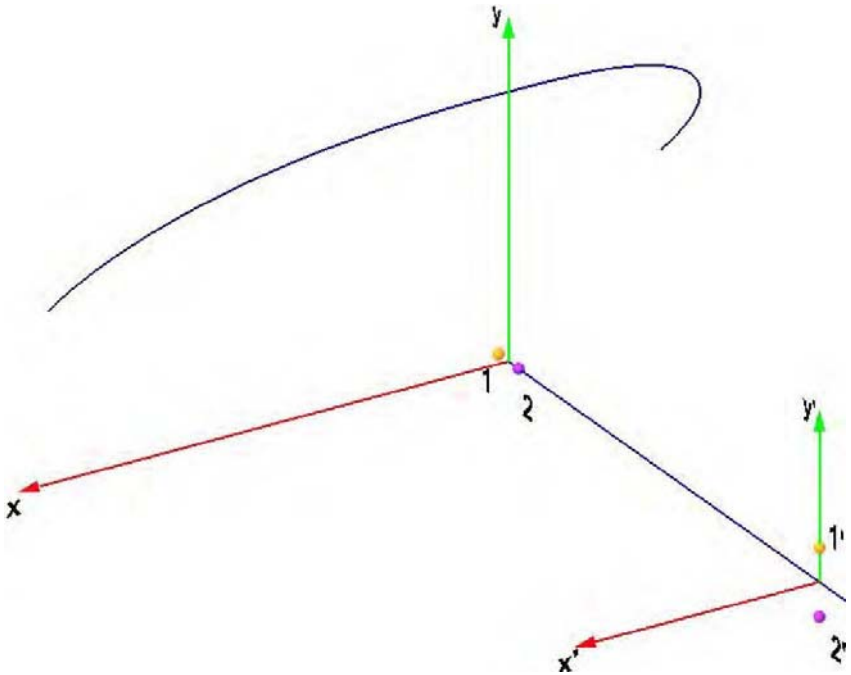




SMS method

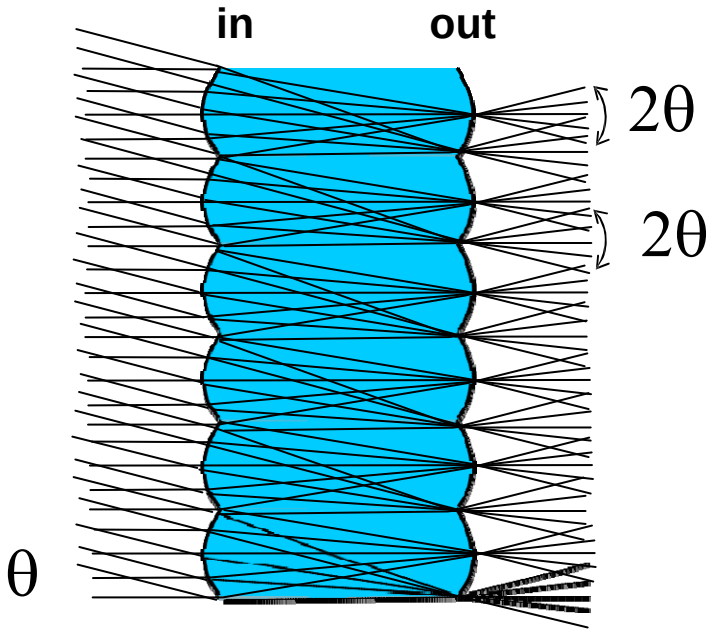


SMS method



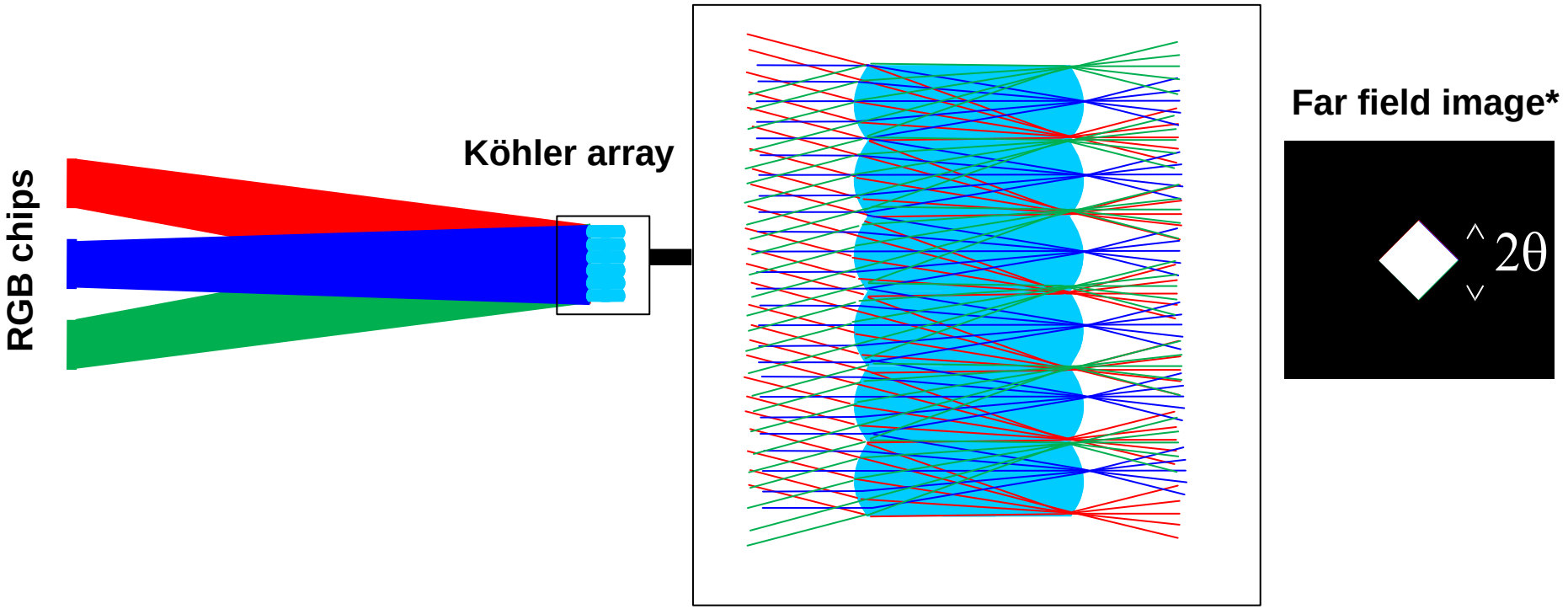
Köhler integration

- **Two-stage design where input/output stage forms image of a preferred object point onto a point of the output/input stage**
- **Canonical example: two identical lenses imaging a point source at infinite (plane wavefronts) onto each other**



Other design tools: Köhler integration

- **When lenses are small and relatively far from the source, the illuminance is uniform over input lenses, so we have uniform intensity between ±θ at the output**



** Square microlenses*

Outline

- Optics and LEDs
- Design methods
- **Design examples**
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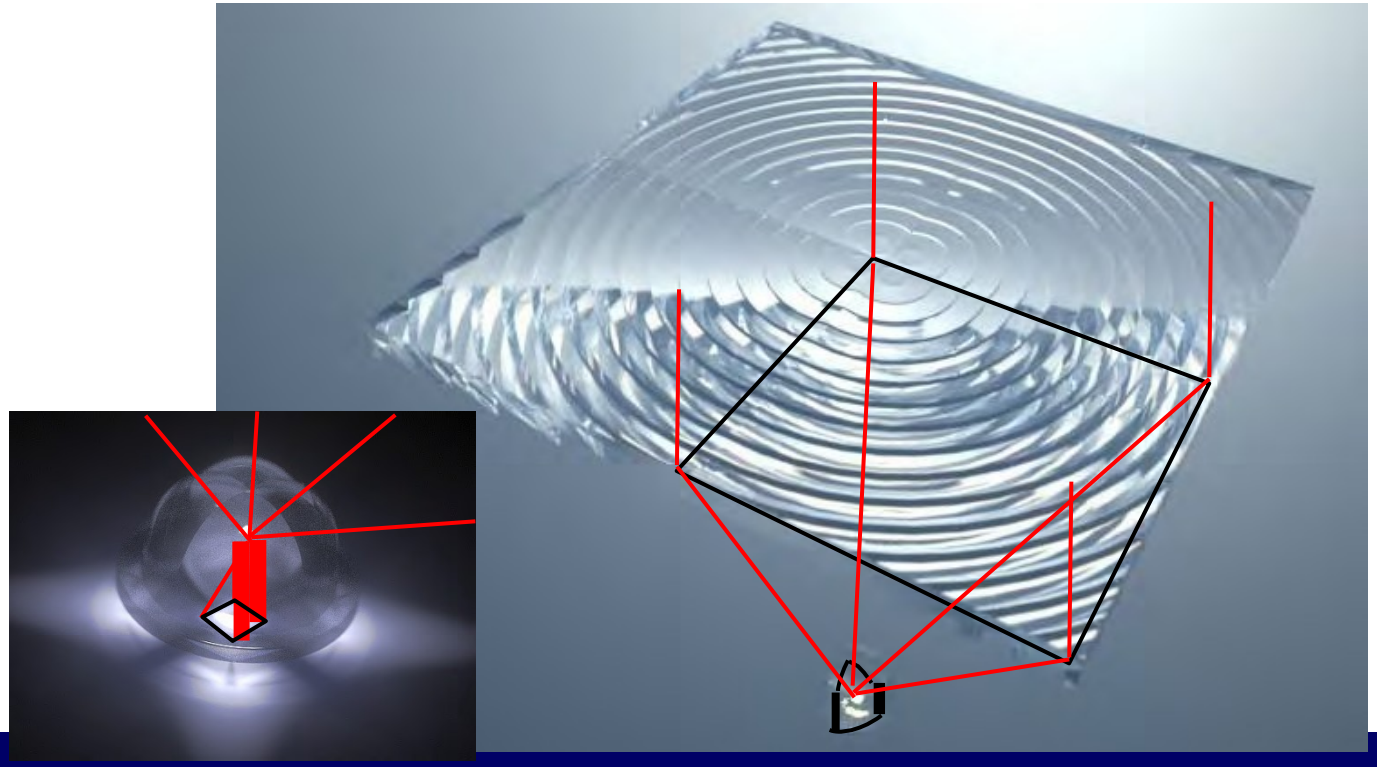
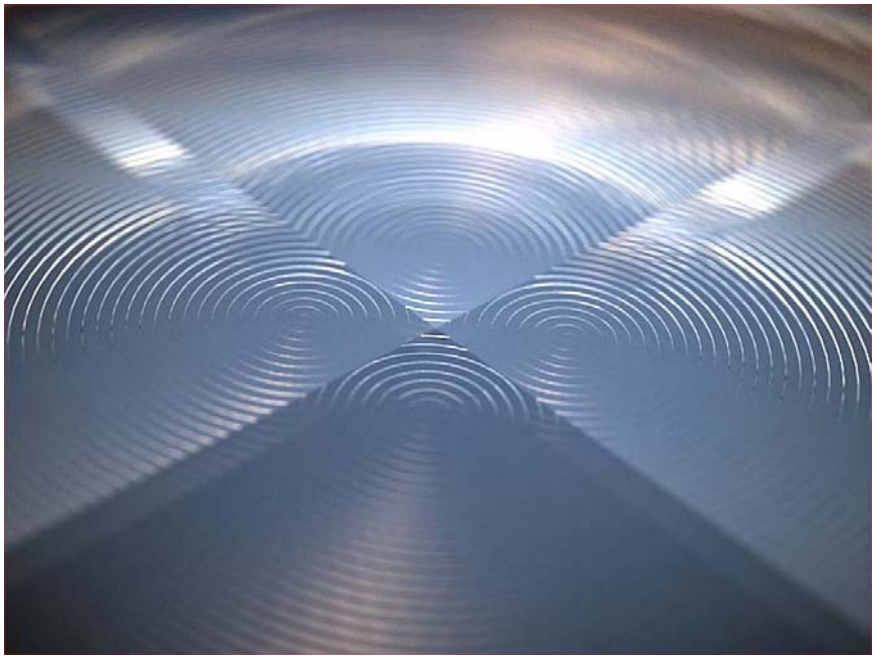
Köhler integration

- **When lenses are small and relatively far from the source, the illuminance is relatively uniform over input lenses, so we have uniform intensity between ±θ at the output**
- **Köhler channels embedded into optics (patented)**

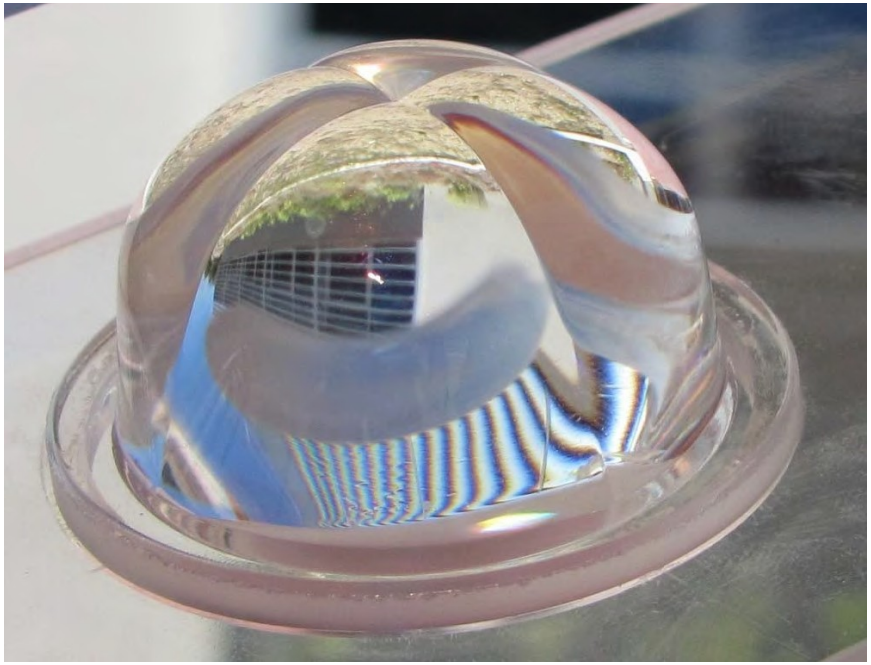


The FK concentrator

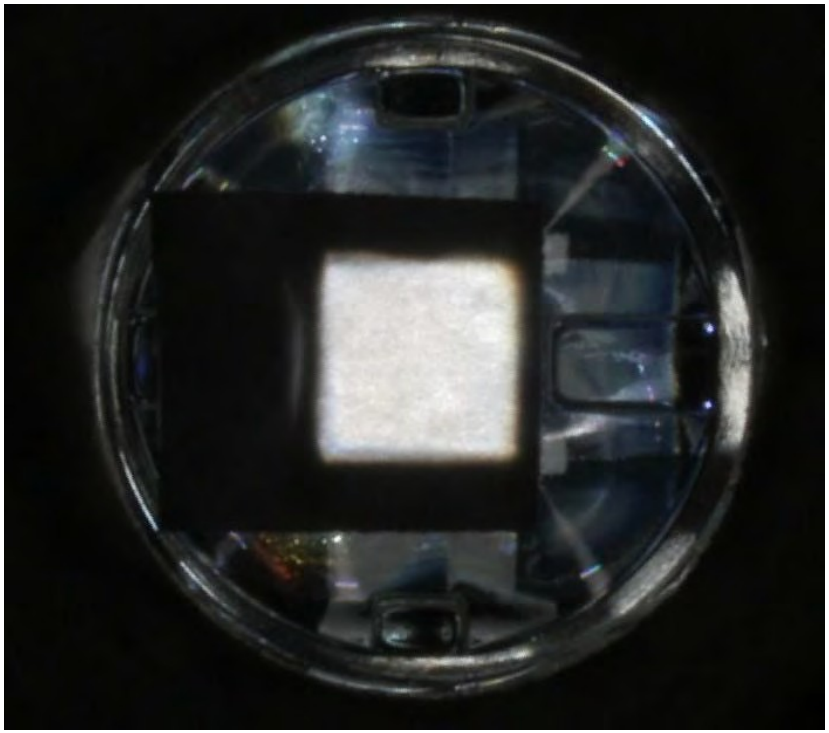
Fresnel lens

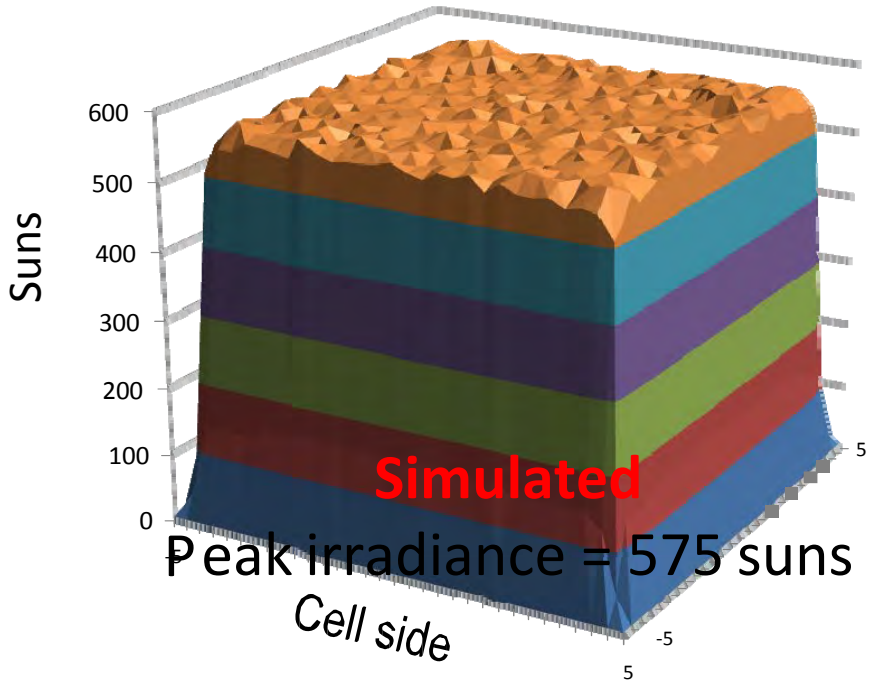


Freeform secondary lens



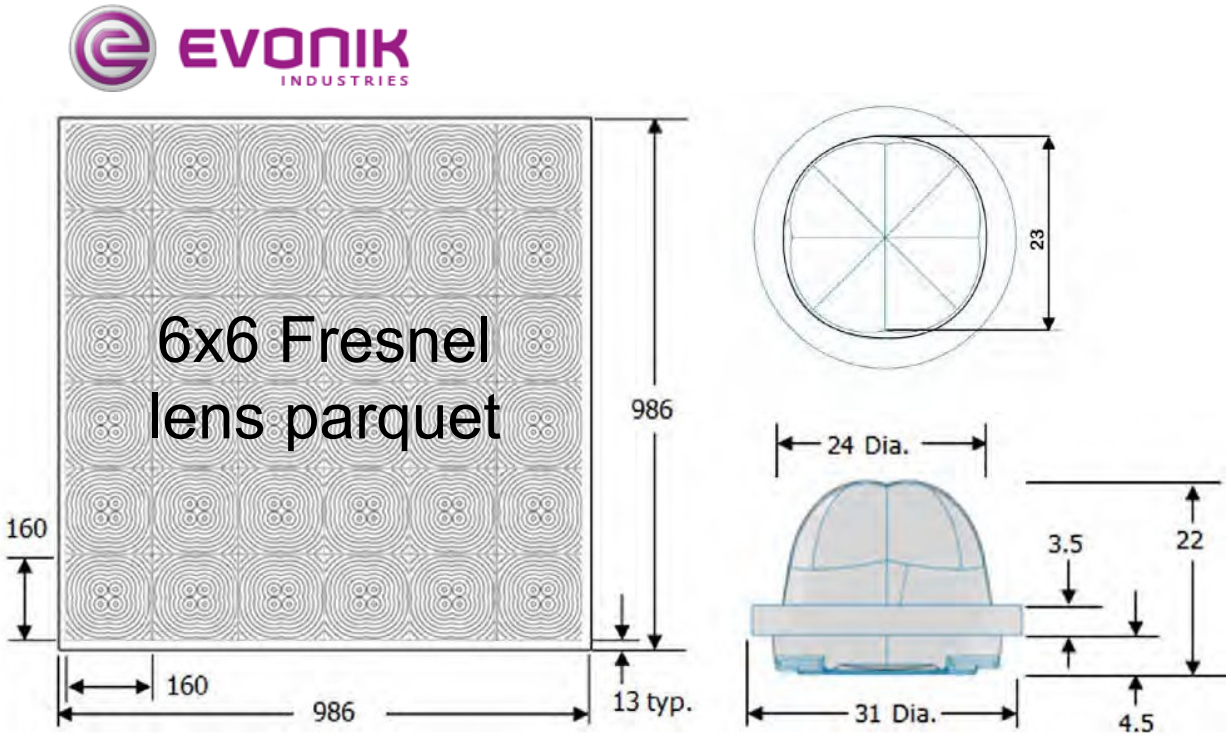
FK irradiance uniformity





The Ventana™ Optical Train

- A complete off-the-shelf optics solution by Evonik and LPI
- Based on the best-in-class design: The FK concentrator



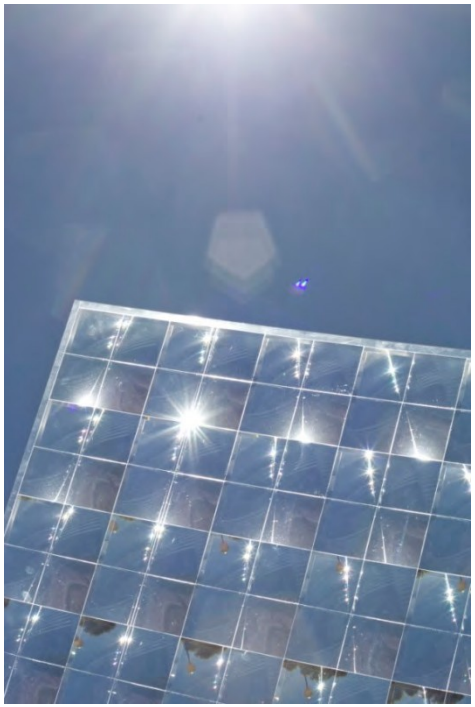
POE = primary optical element

SOE = secondary optical element

The Ventana™ reliability (可靠性)

POE:

- Evonik provides a 25 year warranty



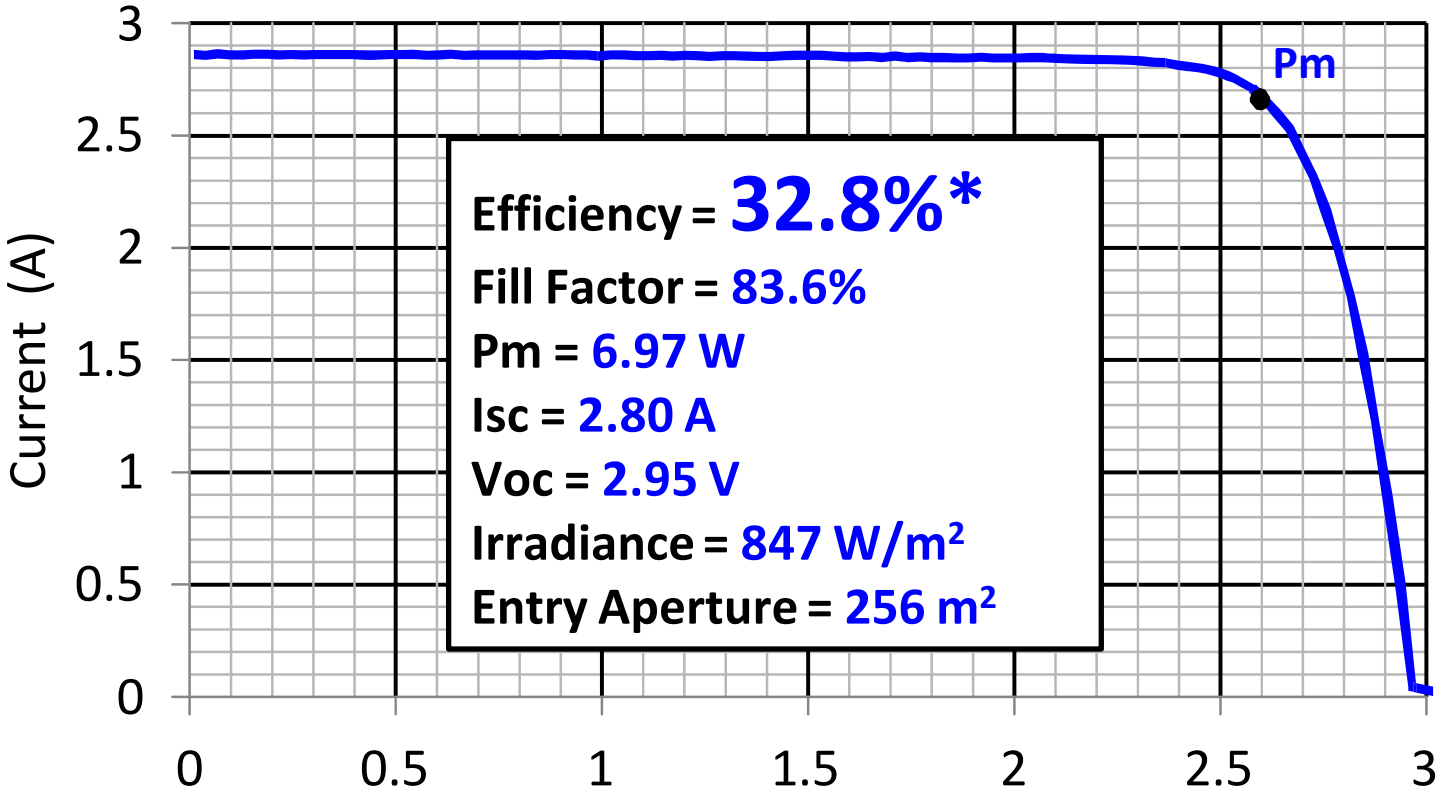
SOE:

- The risk of UV solarization in Ventana™ is greatly reduced by splitting the incident beam into 4 channels.

Silicone:

- Ventana™ encapsulation can use catalist-free silicones, which are the most stable ones.

LPI-Evonik Ventana™ Optical Train

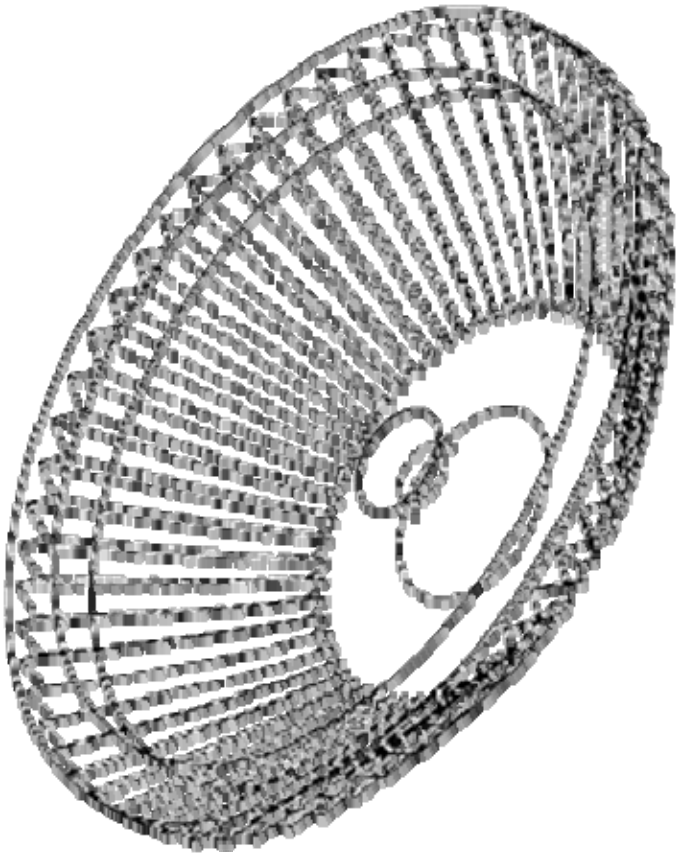


C = 1,024x

$\alpha > \pm 1^{o}$

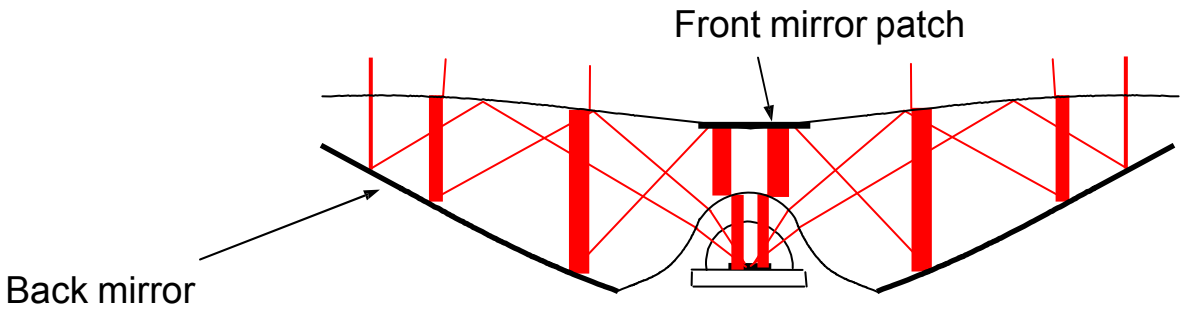
*No AR coatings; @Tcell=25ºC
C3MJ Spectrolab cell bin 39%

LPI V-GROOVE RXI (US patent 8,094,393)



V-GROOVE RXI

- **Ultra-flat RXI collimator**

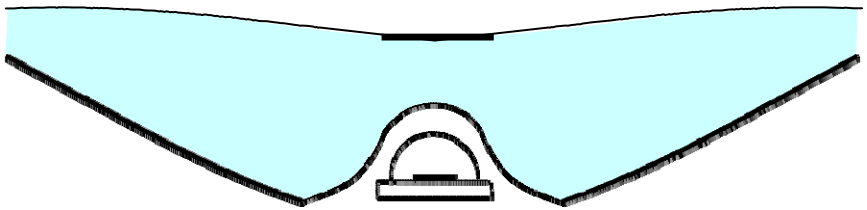


Rays undergo…

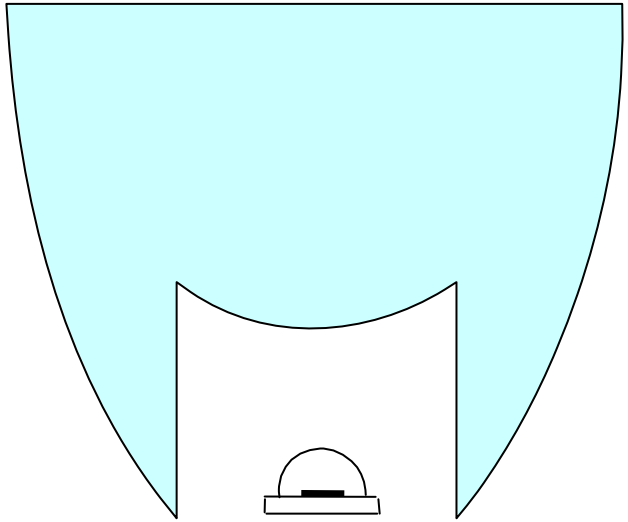
- Refraction (**R**)
- Total **I**nternal reflection (**I**)
- Reflection (**X**)

V-GROOVE RXI

- **Ultra-flat RXI collimator**



RXI



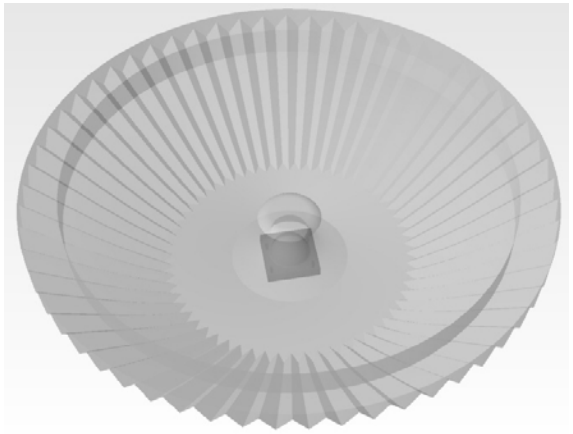
Photon funnel

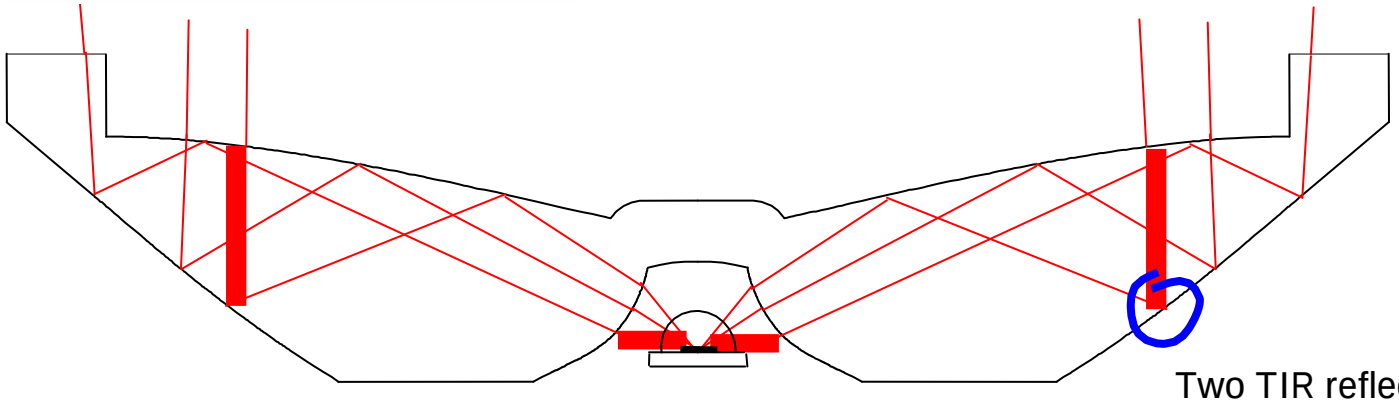
V-GROOVE RXI

- **Ultra-flat RXI collimator**

V-GROOVE RXI

- **Ultra-flat RXI collimator + advanced TIR utilization**

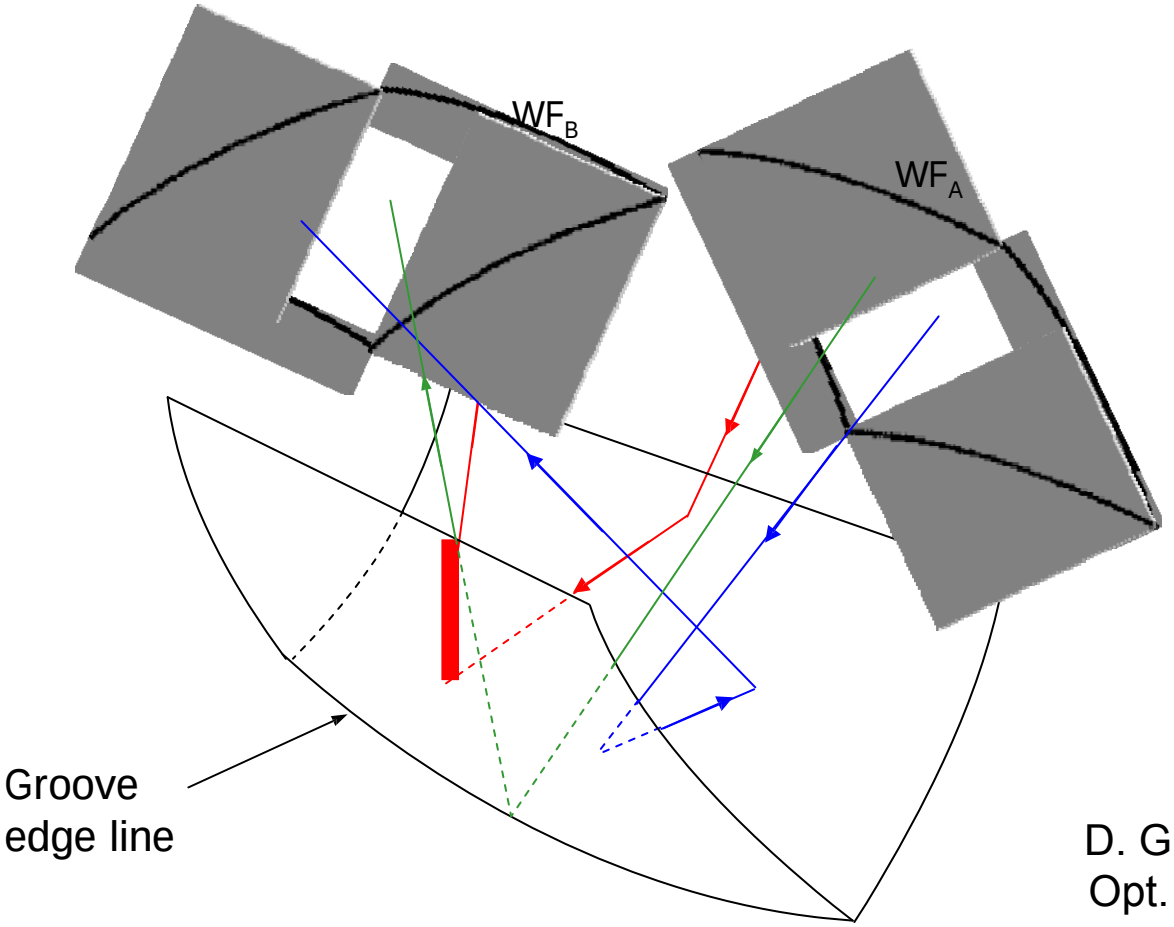




Two TIR reflections

V-GROOVE RXI

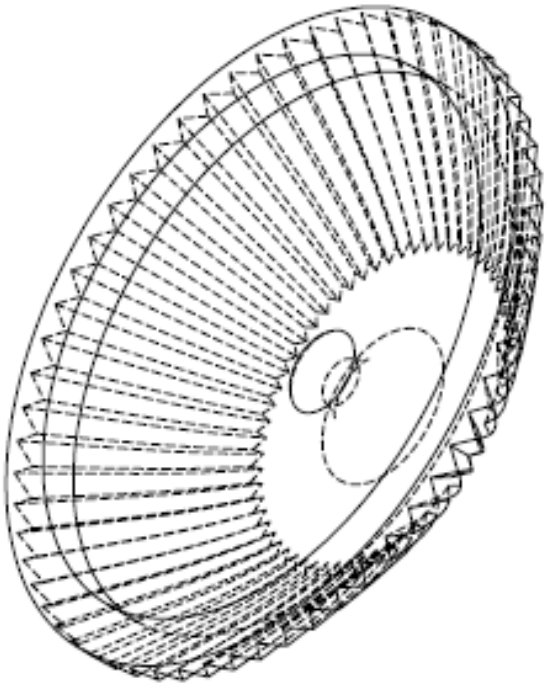
- **Ultra-flat RXI collimator + advanced TIR utilization**



D. Grabovičkić, et al.
Opt. Express 19, (2011)

V-GROOVE RXI

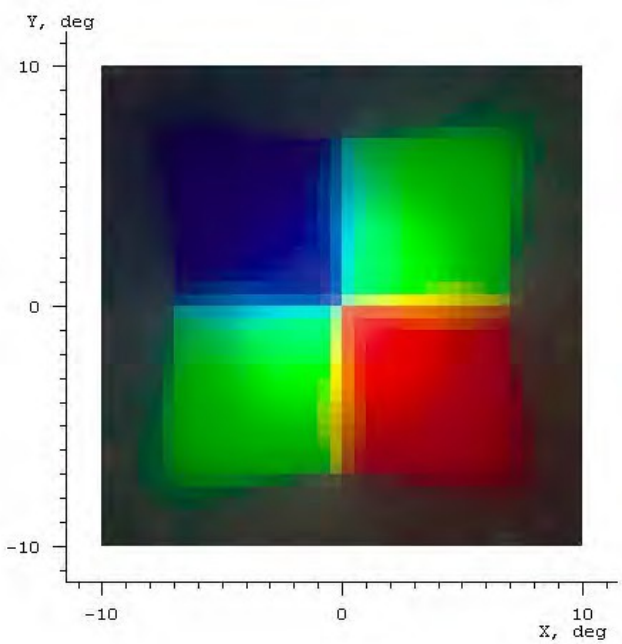
- **Metal-less Dielectric solid**
- **Very flat: depth/diameter = 0.25**
- **High efficiency: LOR = 90%**



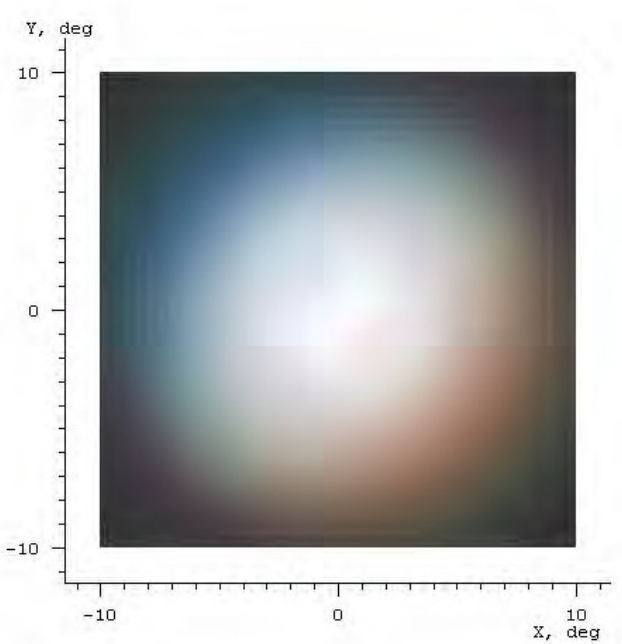
V-GROOVE RXI

- **High collimation**
- **Fits with multi-chip packages: high flux, color mixing feasible thanks to "anomalous deflection"**

RXI + LED RGGB: Far field pattern (ray trace)



Original RXI

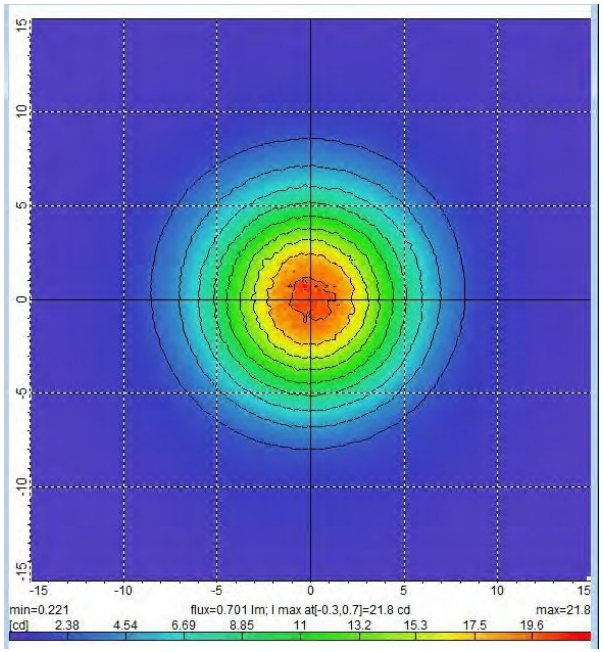


V-Groove RXI

V-GROOVE RXI

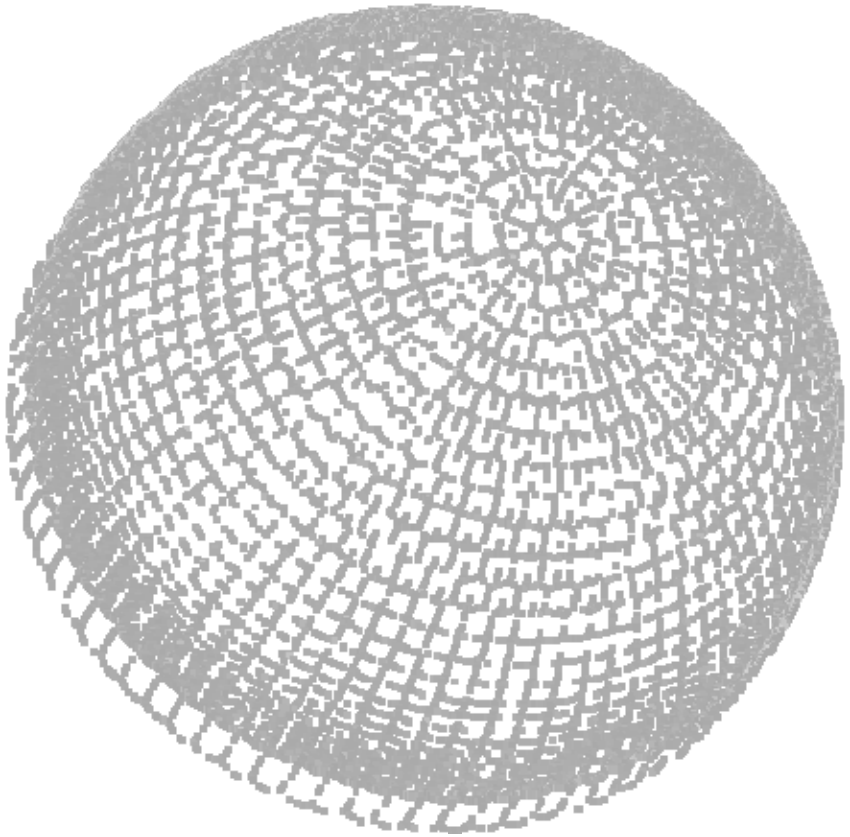
- **High collimation**
- **Fits with multi-chip packages: high flux, color mixing feasible thanks to "anomalous deflection"**
- **Prototype photometry fits with simulations**

Far field pattern picture



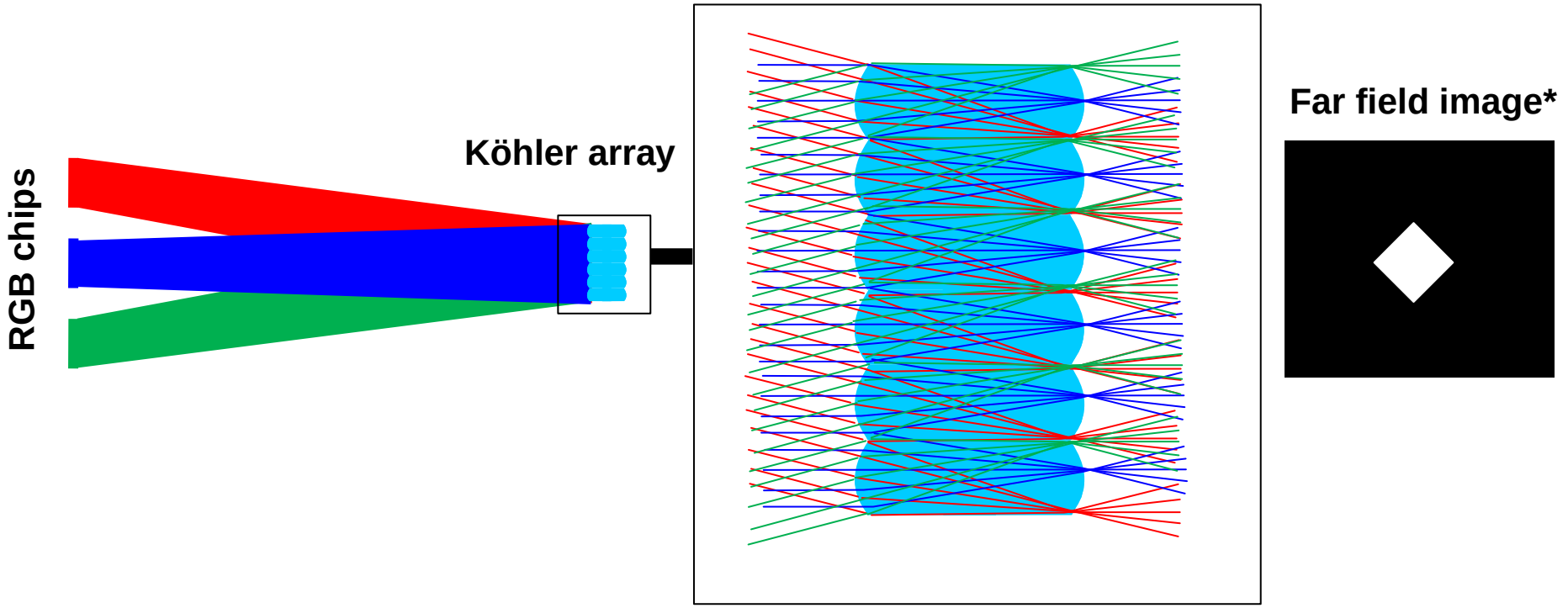
Far field measurement

LPI SHELL MIXER (PCT/US2811/052679)



KÖHLER CHANNELS

- **Aligned arrays of lenses on the inner and outer surface of shell**
- **For every direction, the observer sees an apparent source with all chips welded**



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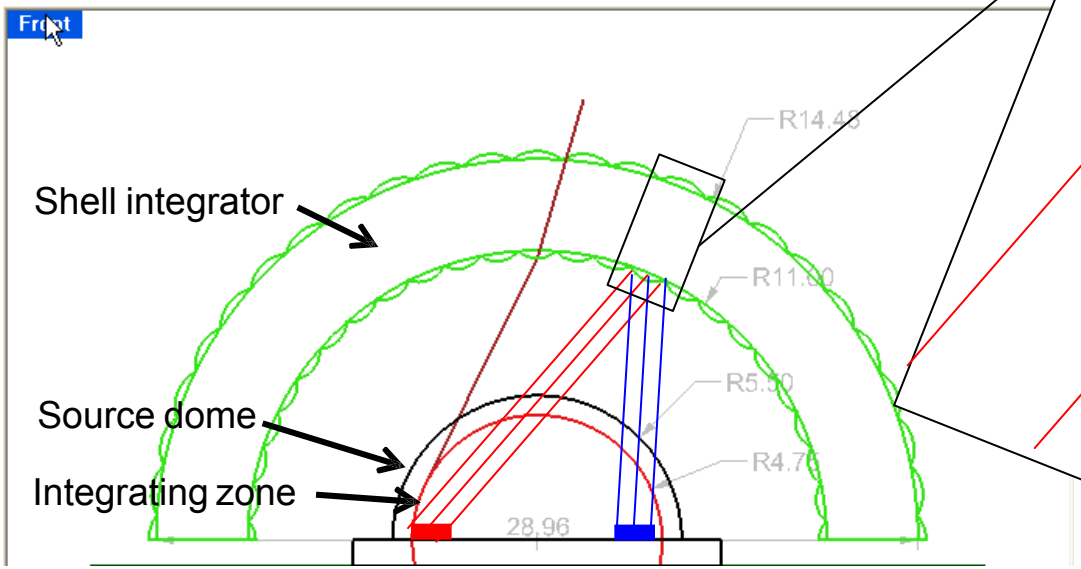

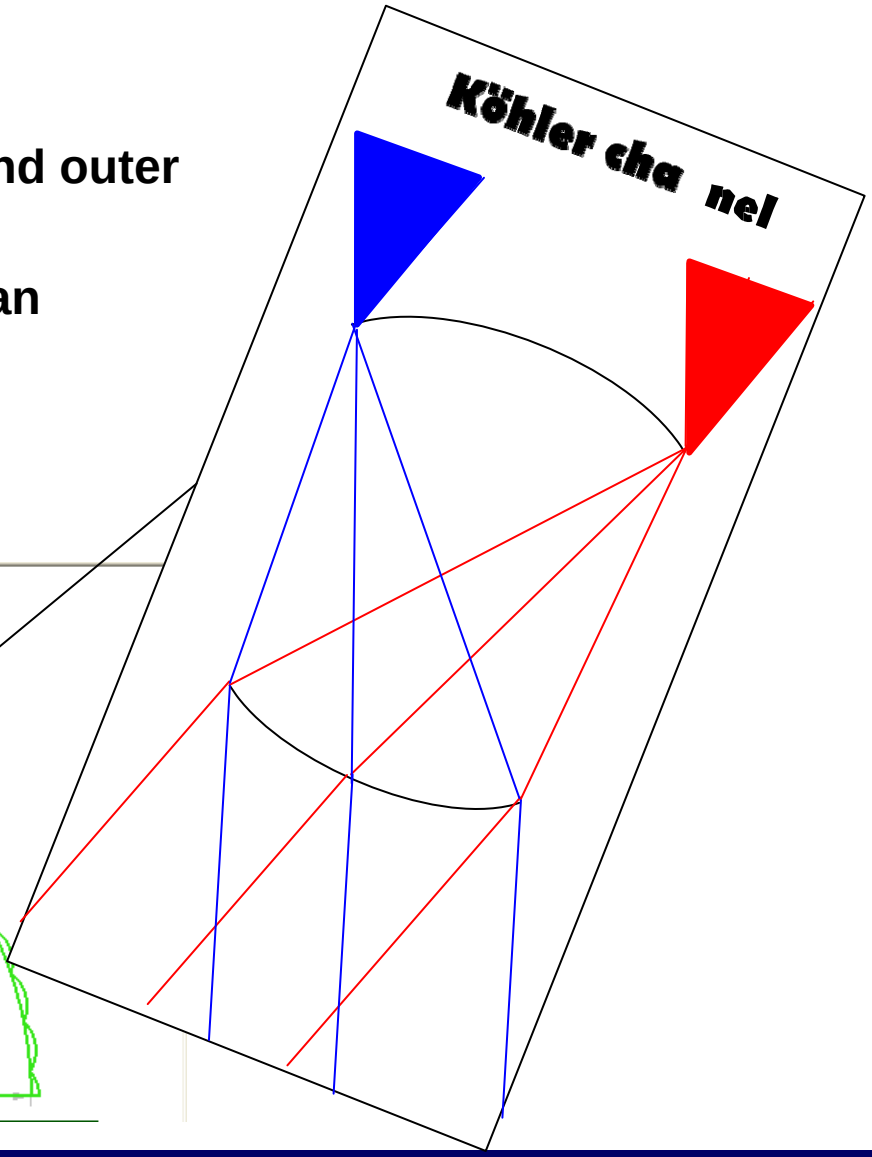

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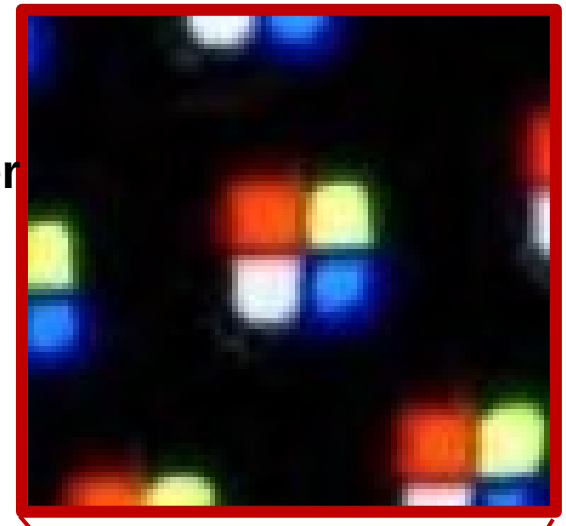
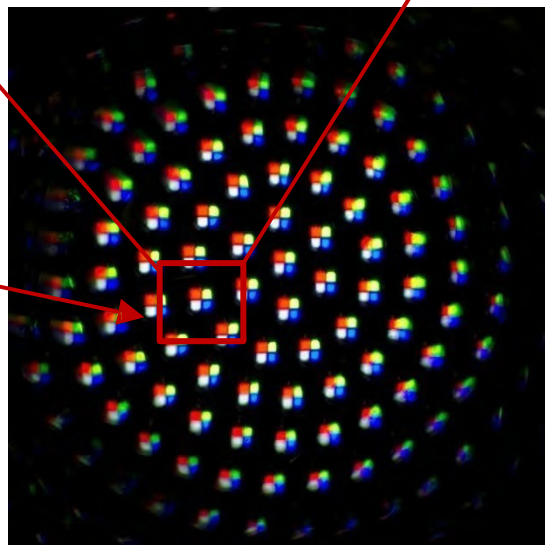
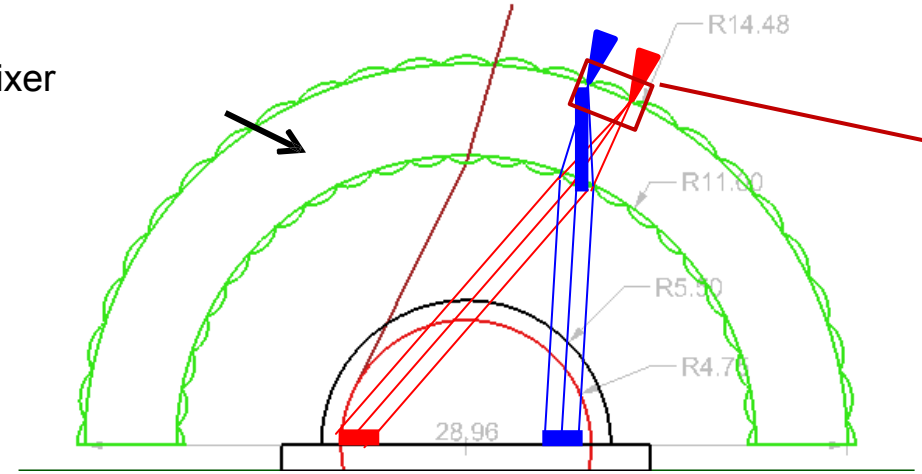
- **For every direction, the observer sees an apparent source with all chips welded**





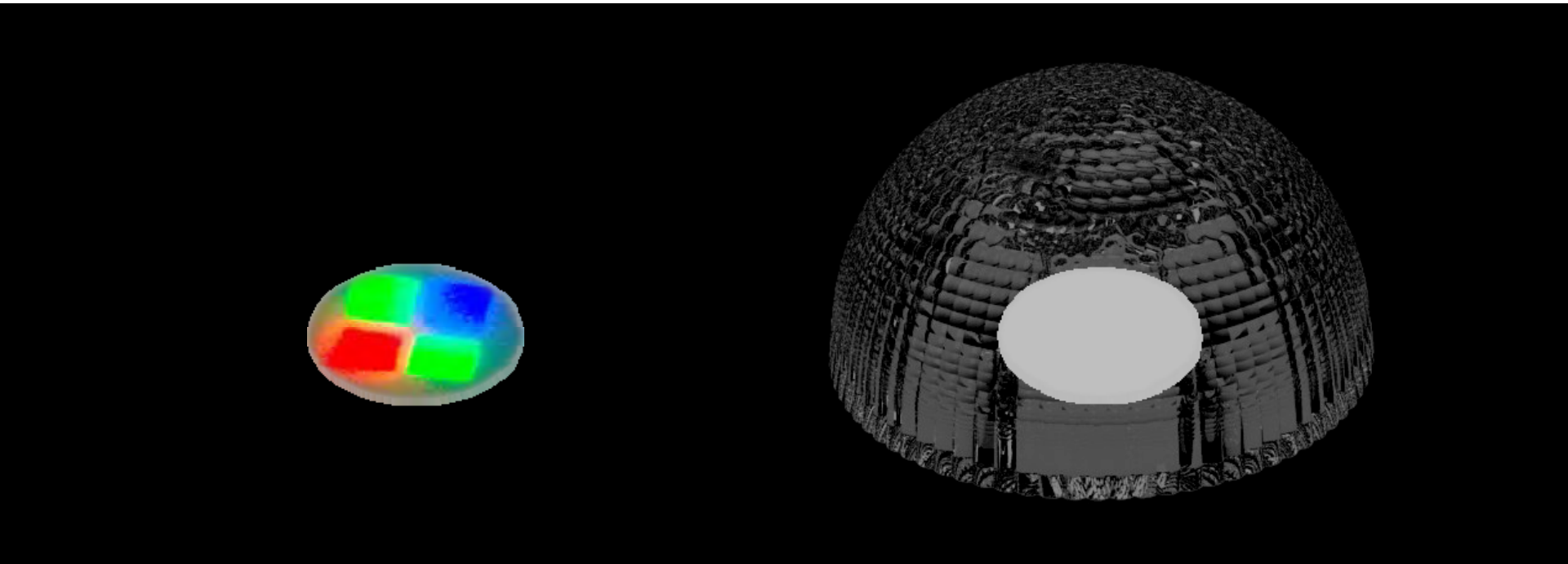
Shell mixer



LPI SHELL MIXER

•**Features**

- **Hemispherical Köhler design for an universal Light engine**
- **Light is integrated in optical channels**
- **Preserves source apparent size and welds all chips within the integration zone (color mixing)**



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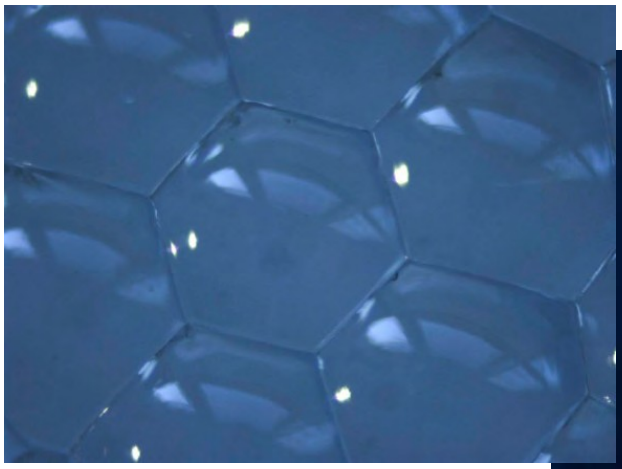

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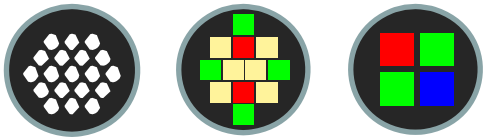
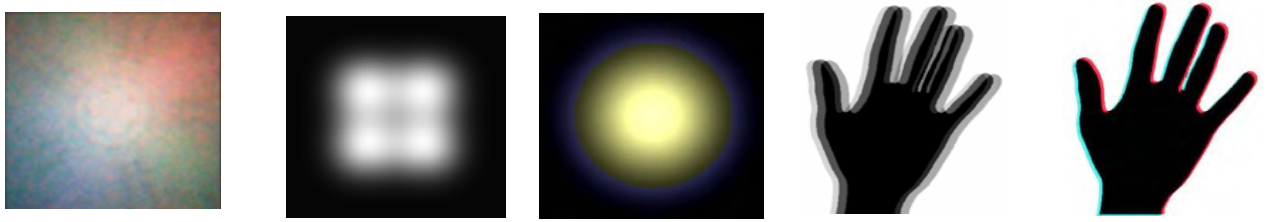


+ luminaries



White point shift | Intensity Artifacts | Color Fringes | Multiple Shadows | Color Shadows

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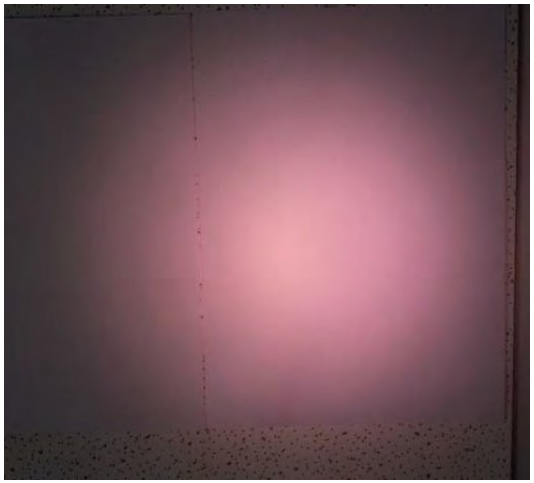
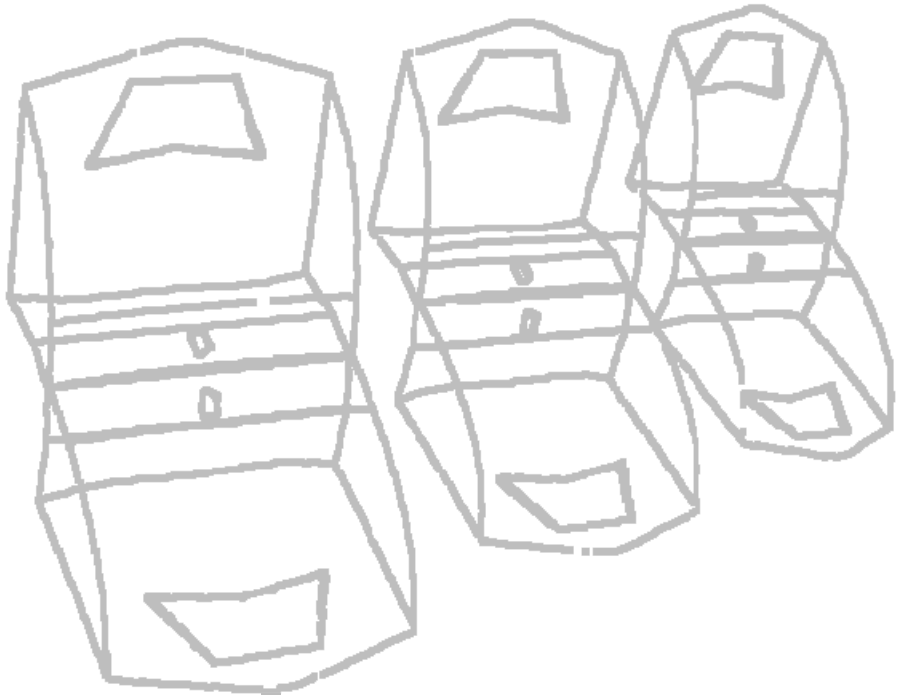
Without shell



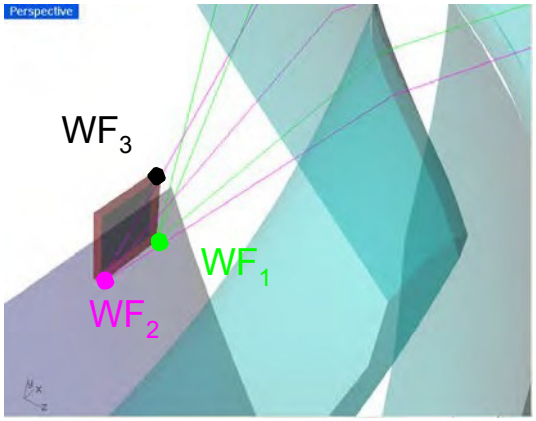
With shell

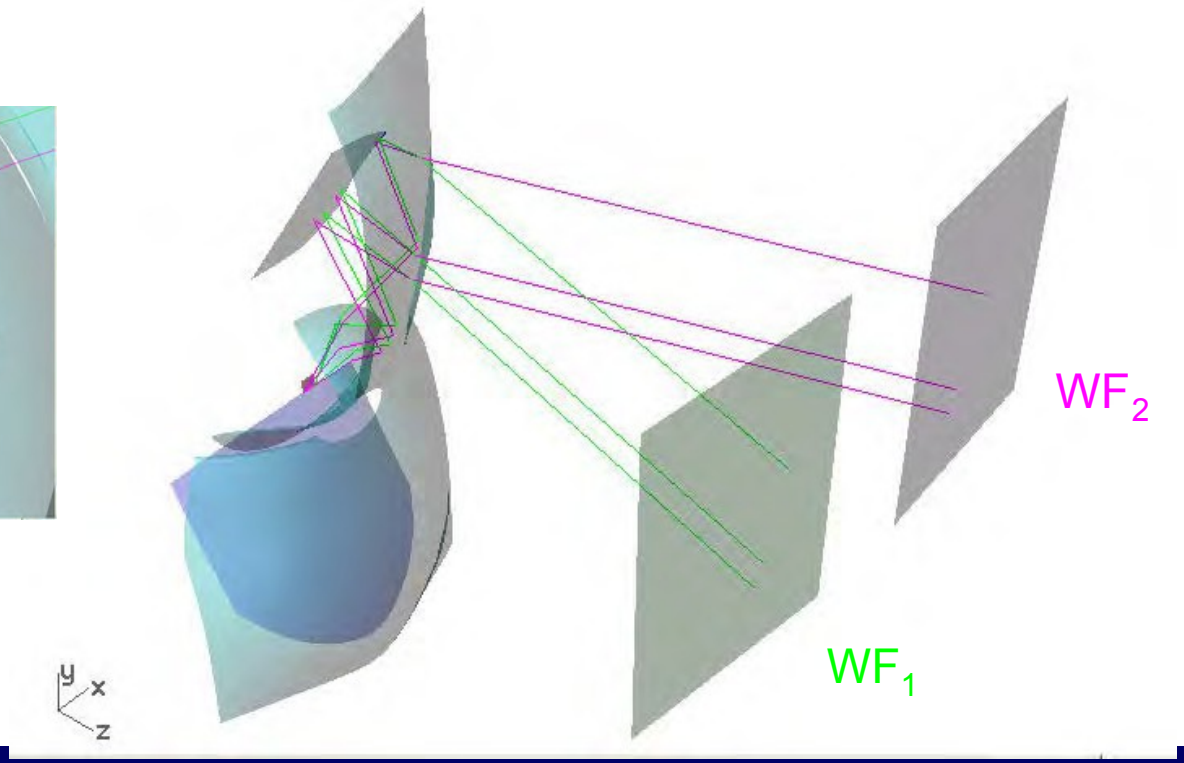
LPI FREE-FORM RXI (US PATENT 7,460,895)



FREE-FORM RXI

- **SMS 3D design**
- **Connects a extended source bundle with an asymmetric pattern**
- **Compact + high efficiency**





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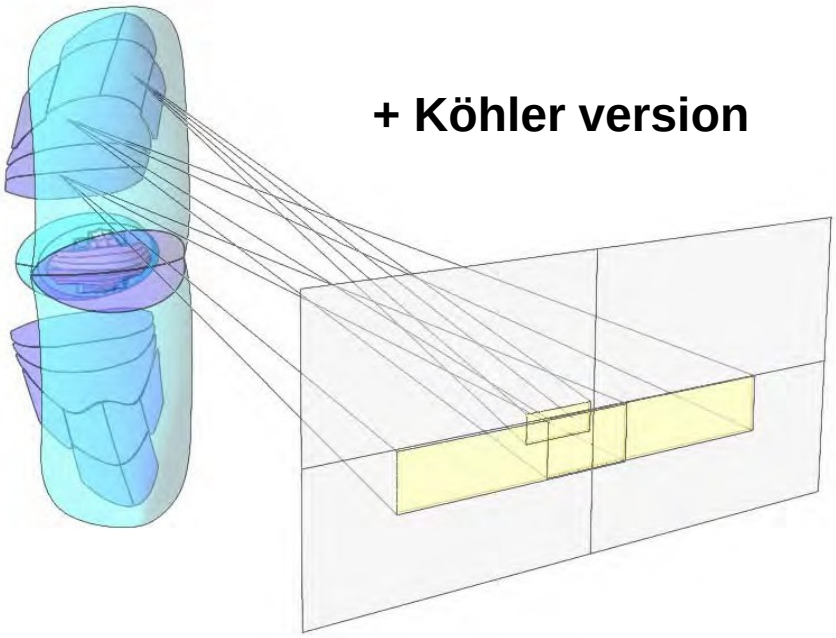
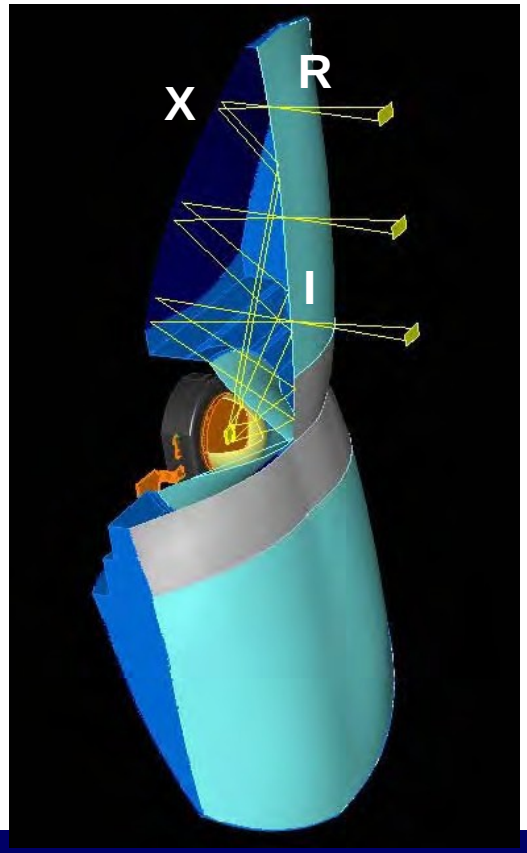
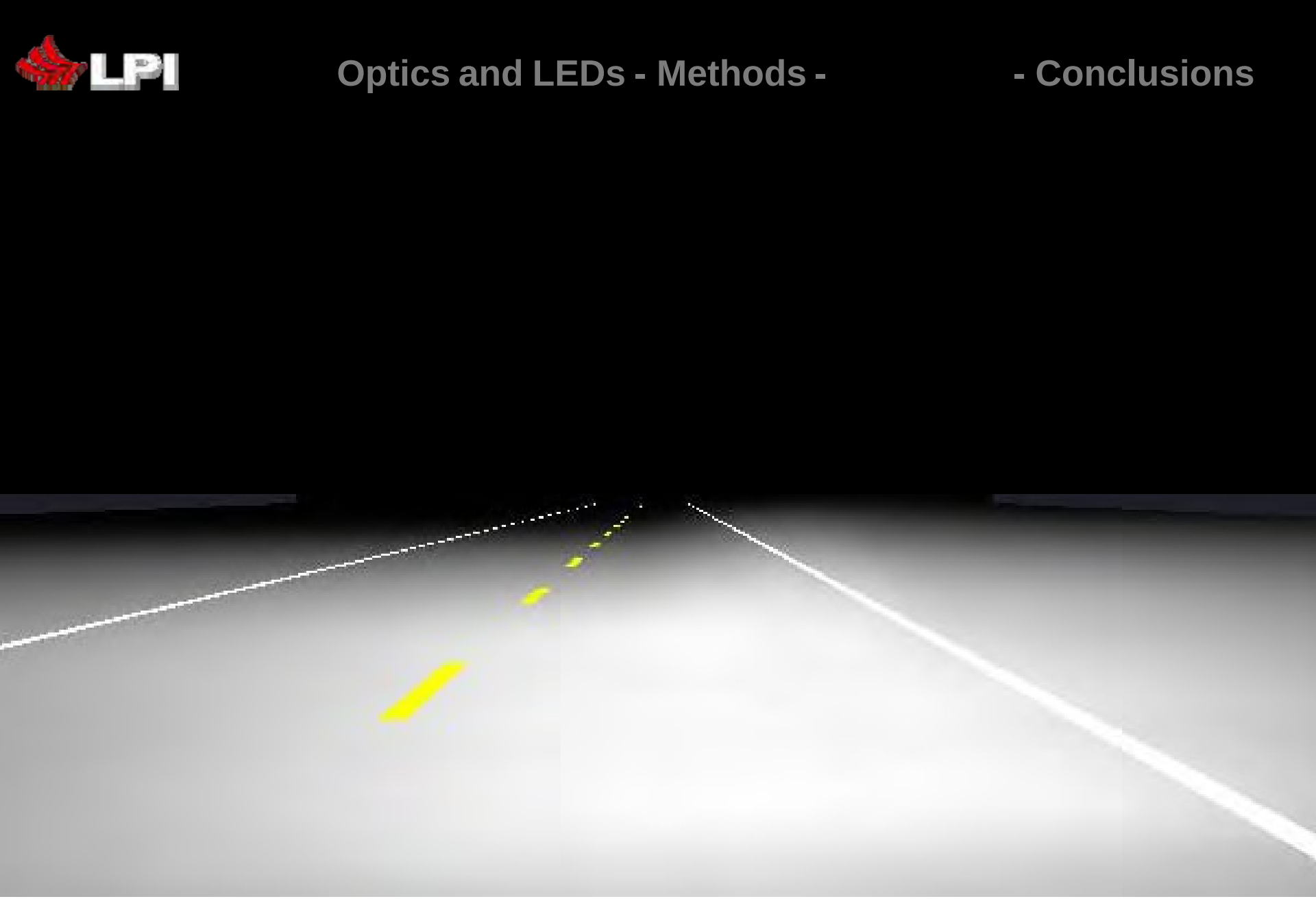


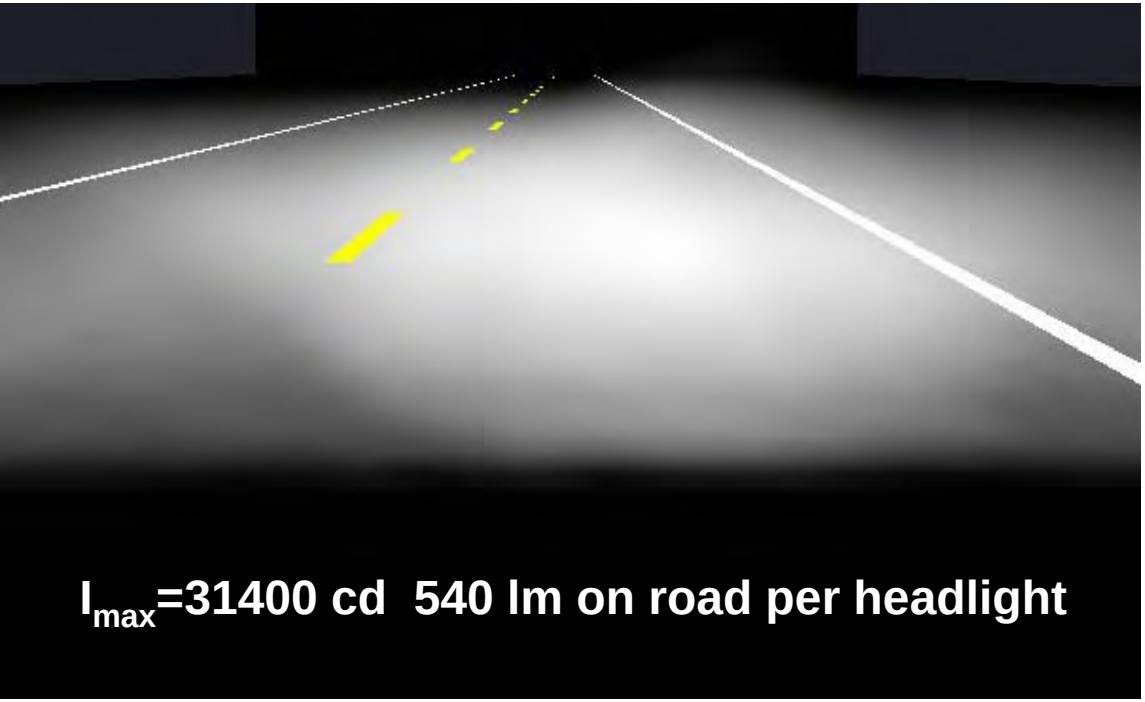
+ Köhler version

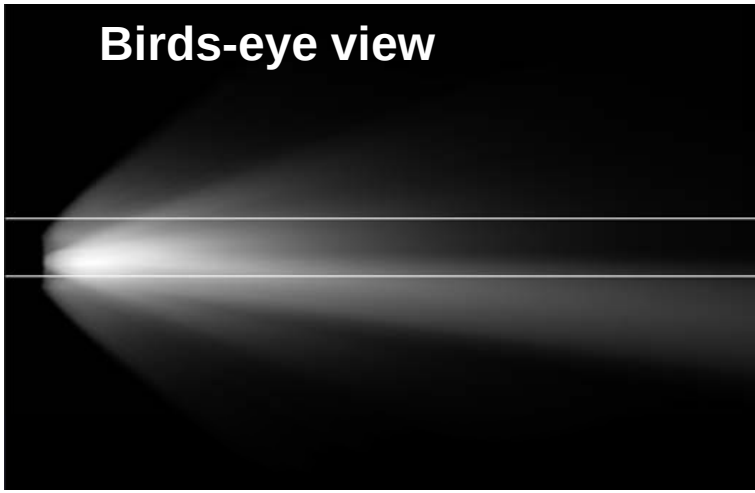




FREE-FORM RXI

- **High-end applications**
- **Low beam: complex illumination problem owing to radical asymmetries, high flux on the road, sudden intensity drops (cut-off line)**
- **Standard pattern**

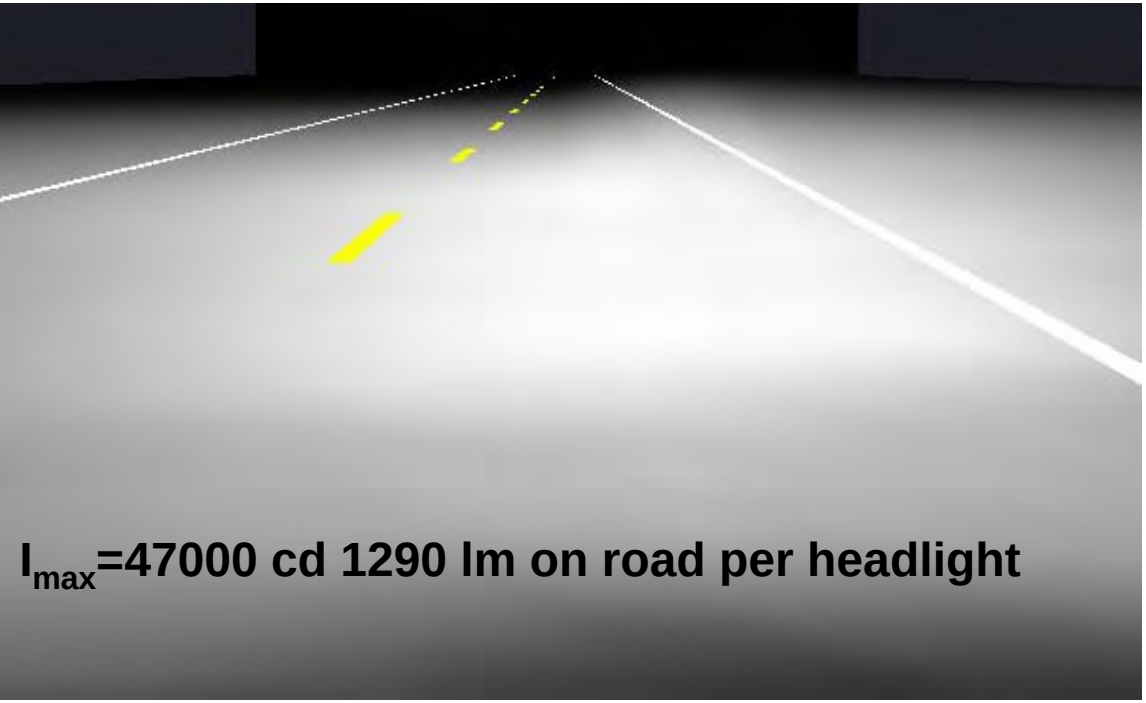


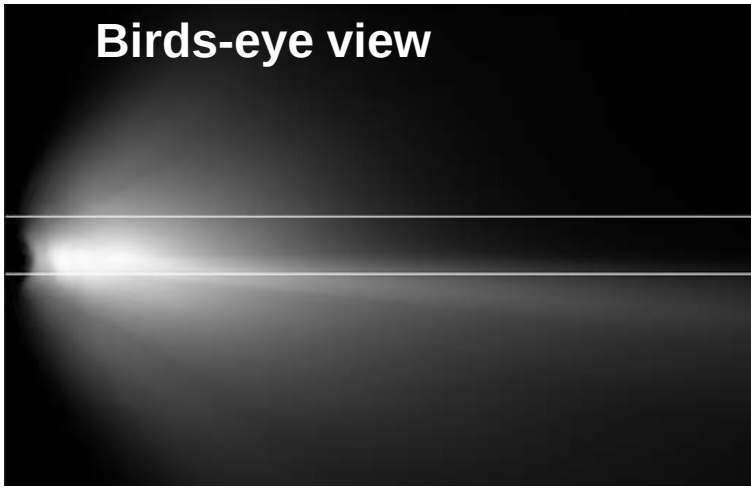


Halogen-based low beam

FREE-FORM RXI

- **High-end applications**
- **Low beam: complex illumination problem owing to radical asymmetries, high flux on the road, sudden intensity drops (cut-off line)**
- **RXI pattern**



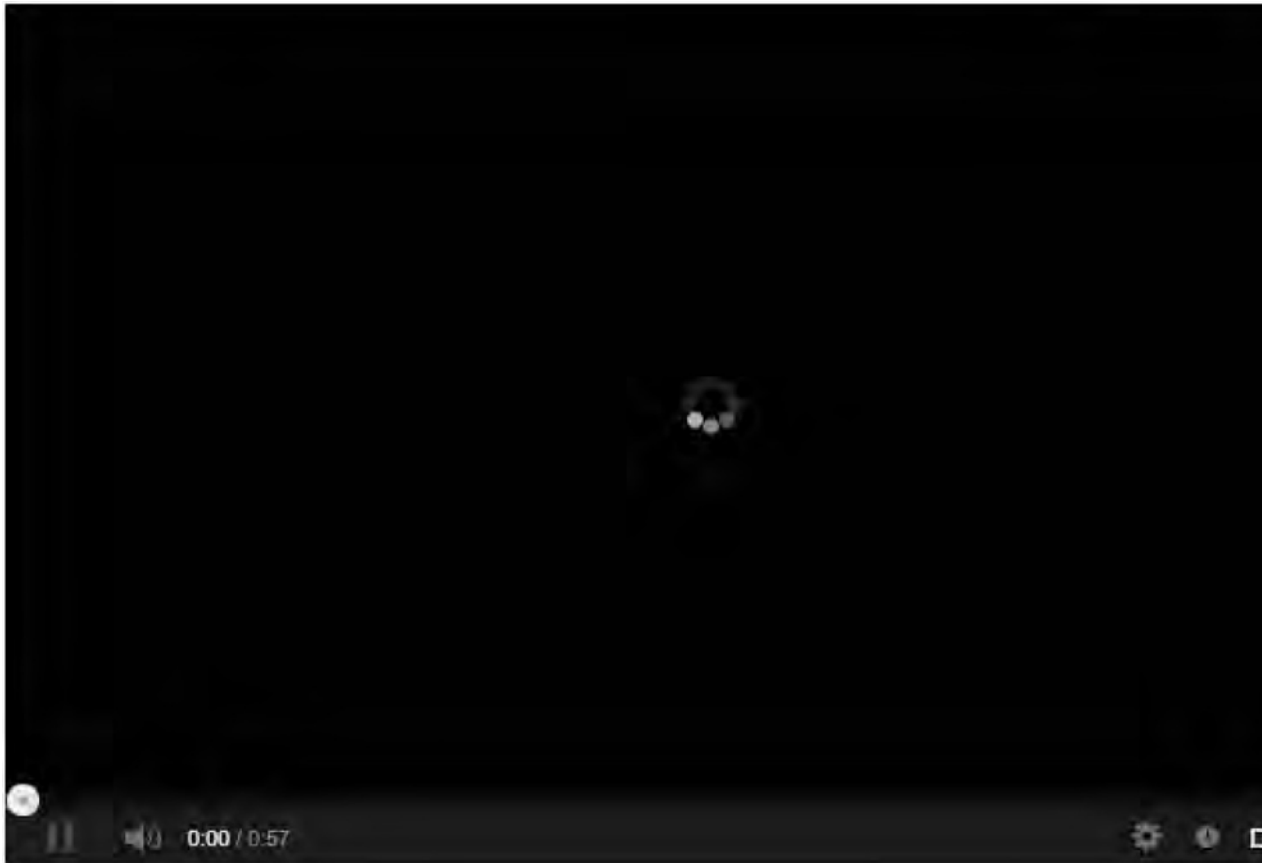


LPI free-form RXI


R8
Vorsprung durch Technik
HH BA 740


LEXUS

GUIA

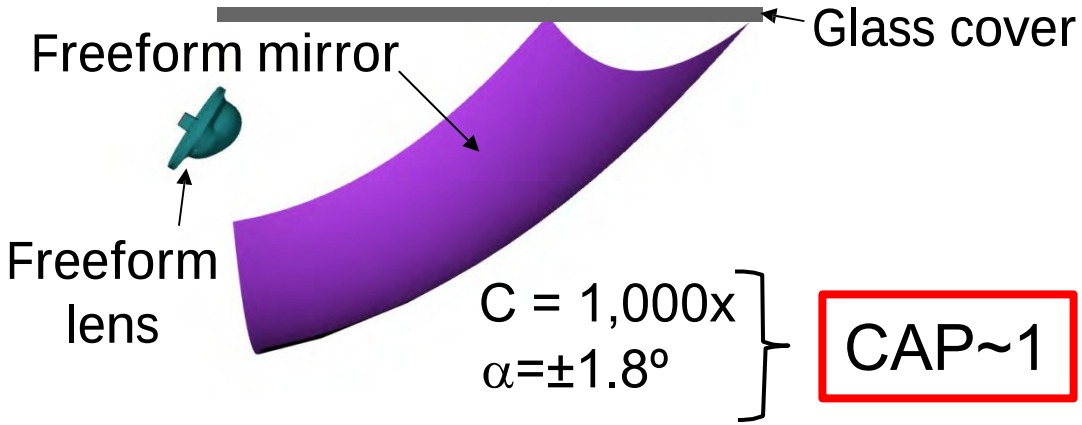


ewel Eye ™ LEO Headlights

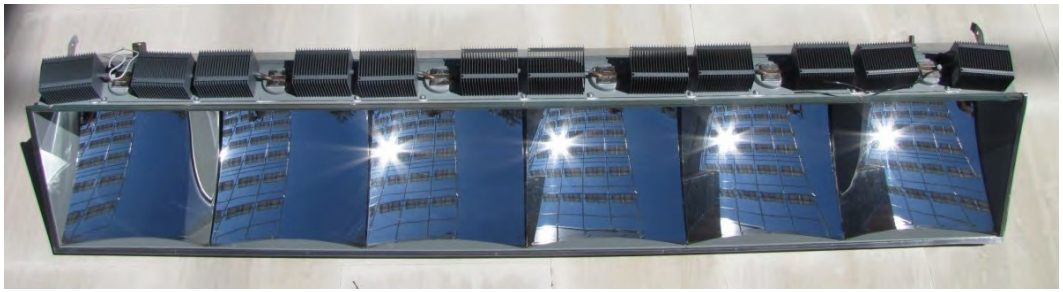
Acura 420 vkfeos

Suscrito

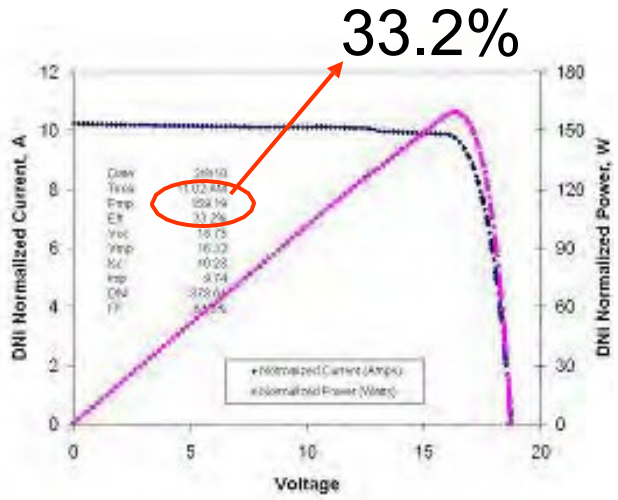
A CPV example: The freeform XR concentrator

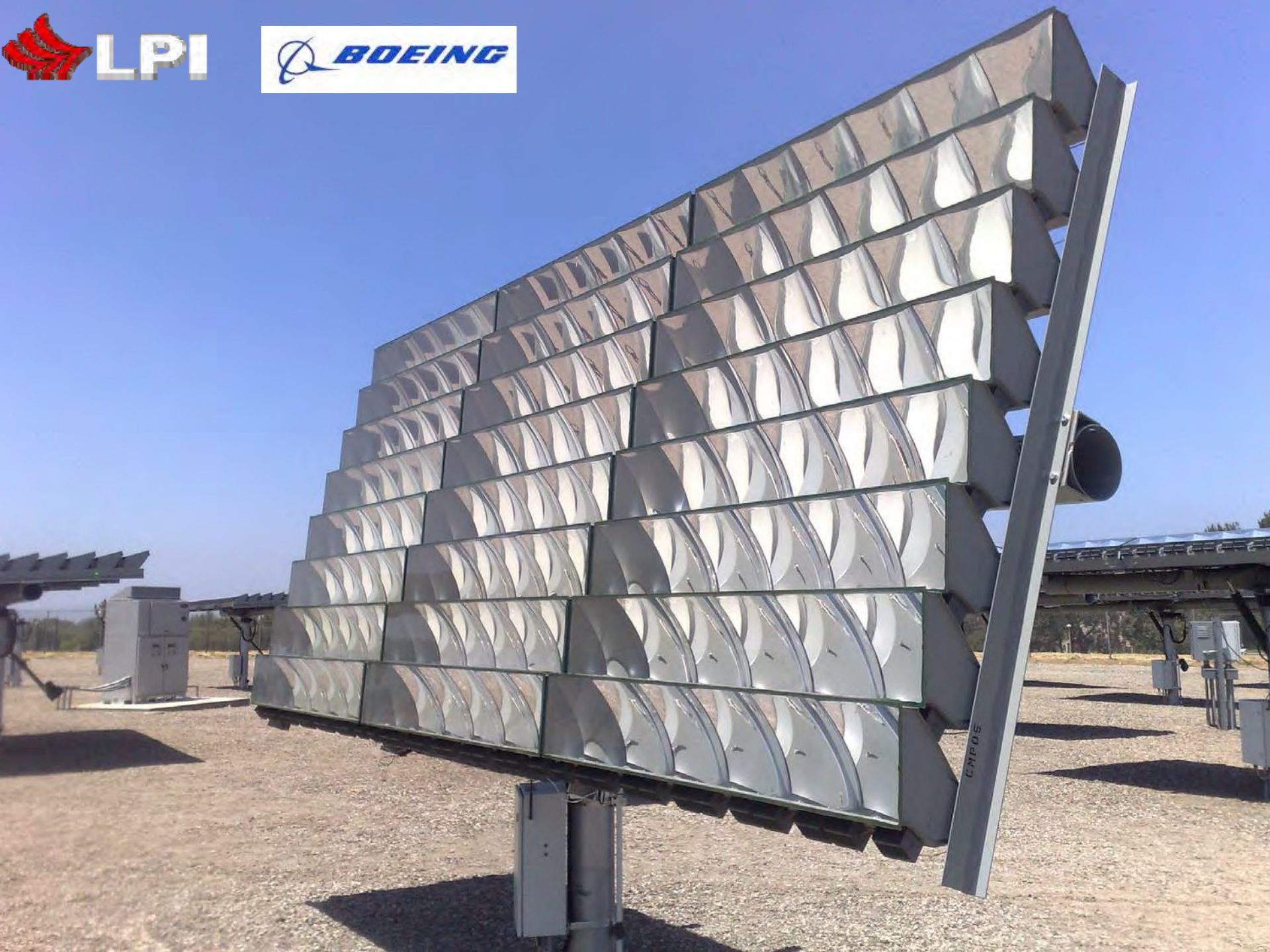


A. Cvetkovic, M. Hernández, P. Benítez, J. C. Miñano, J. Schwartz, A. Plesniak, R. Jones, D. Whelan, Proc. SPIE Vol. 7043-12, 2008



* The XR700 module developed by BOEING Co. and LPI
(*A.Plesniak et all*. 34th IEEE PV Specialist Conference, 2010)




LPI
BOEING

- **SSL to dominate the market by 2020**
- **SSL and Nonimaging optics marry well**
  - **More performance**
  - **More tolerance**
  - **Simpler parts (mass production)**
  - **Lower Costs**

Acknowledgments:

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More information at project website http://ssl4.eu

Thank you